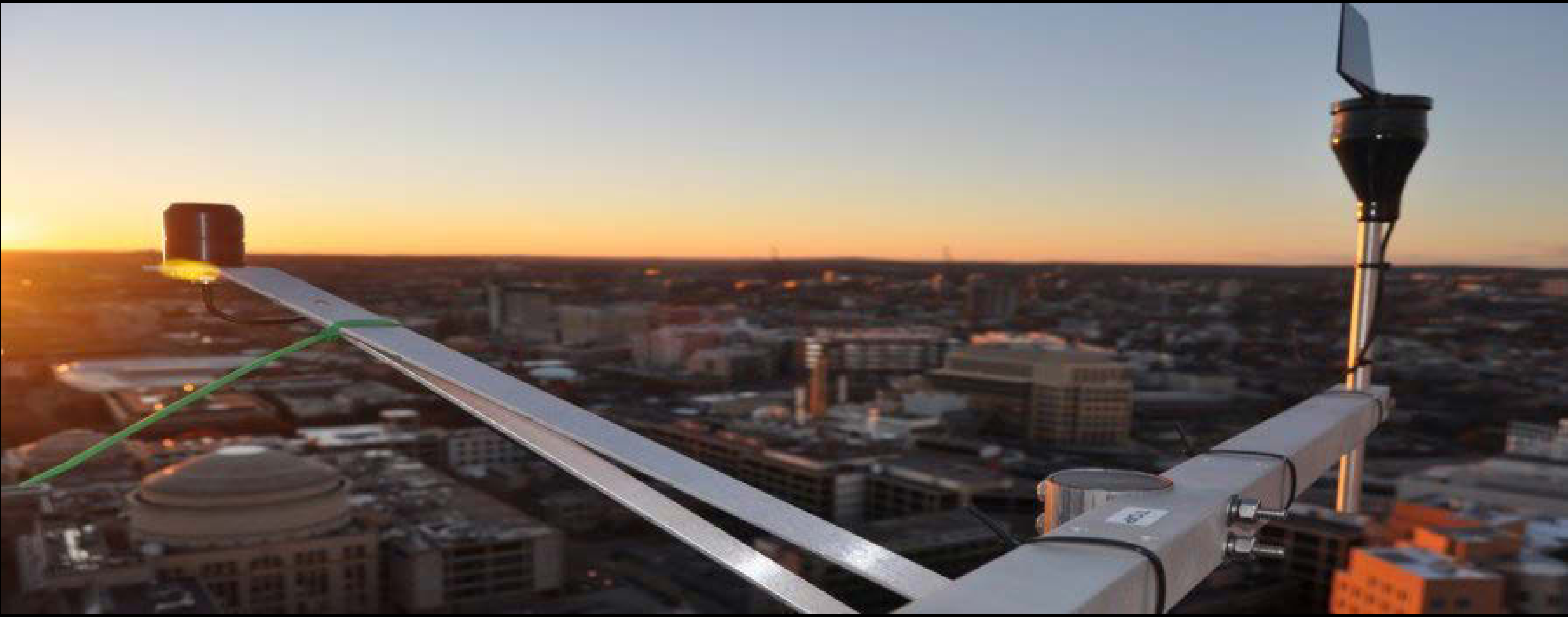
4.401/4.464 Environmental Technologies in Buildings



Old weather station on the roof of the MIT Green Building

Christoph Reinhart

L03 Understanding Climate – Solar Radiation

MIT SDLAB

Today's Learning Objectives

To understand:

- ❑ How local microclimate is measured.
- ❑ The amount of solar radiation worldwide.

Measuring Climate

What do you think we should measure?

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Climate Data

You should start developing a feeling for typical inside and outside levels.

Dry Bulb Temperature [°C]

Relative Humidity [%]

Direct Solar Radiation [W/m²]

Diffuse Horizontal Solar Radiation [W/m²]

Wind speed [km/h]

Wind direction [Degree]

Cloud Cover [%]

Rainfall [mm]

Weather Station

MIT Building 1

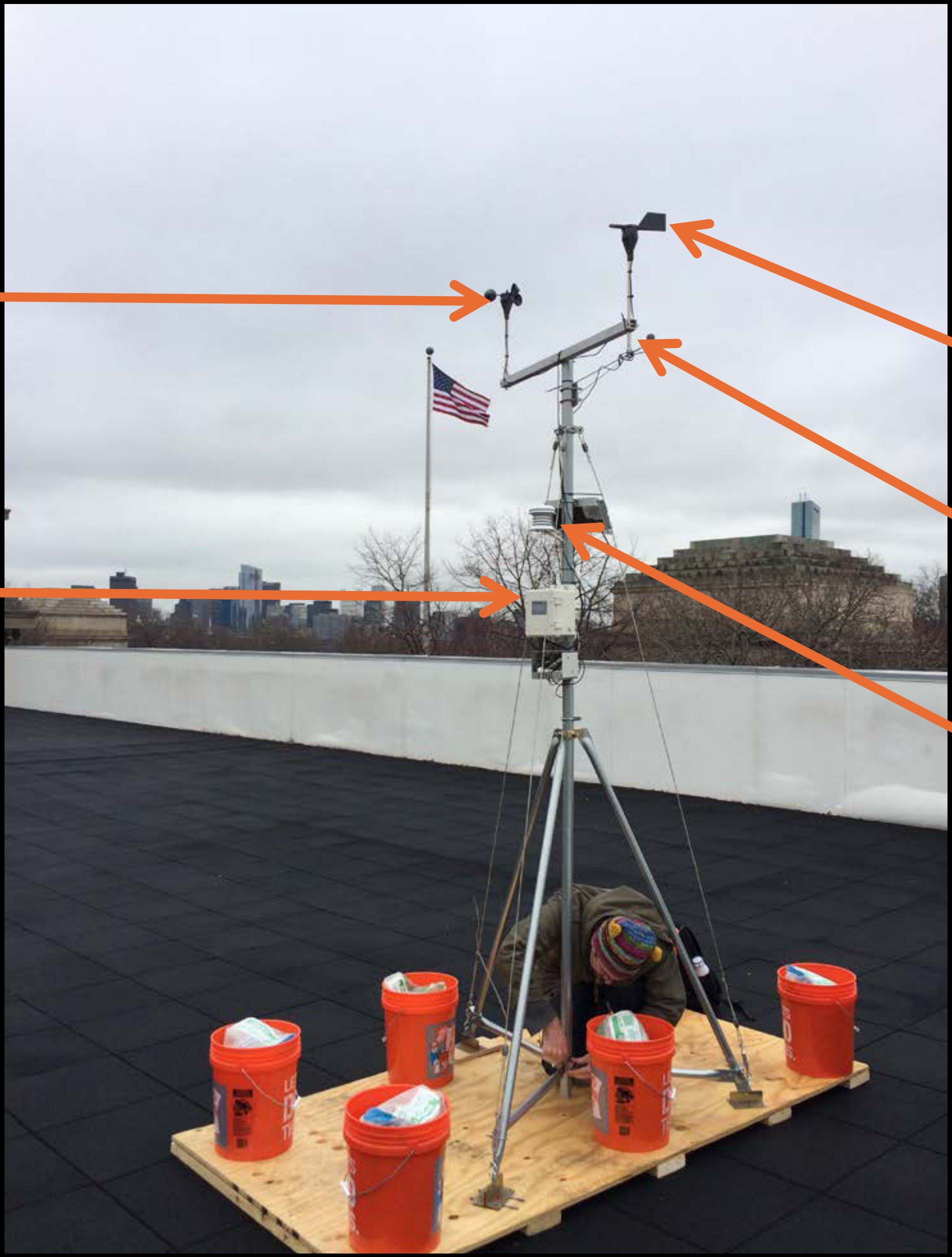
Wind Speed
(cup anemometer)

Wind Direction (vane)

Solar Radiation

Data Logger

Temperature & Relative Humidity

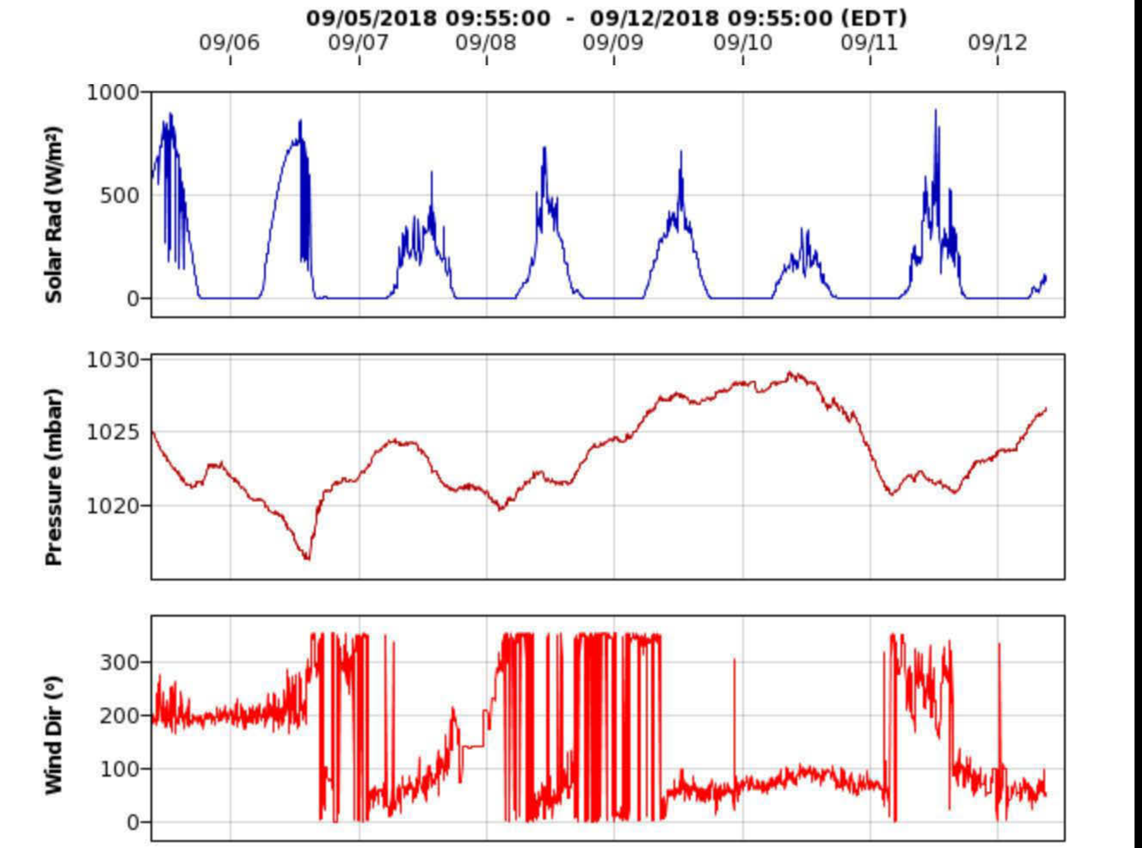


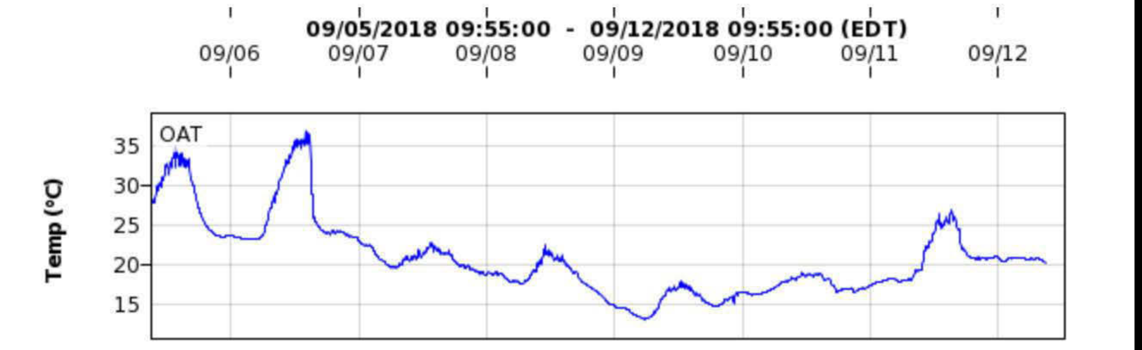
Hardware Costs ~$2000 (2008)

(Weather Station Starter Kit $1214; Tripod Kit $245; Hobo Software $99; 2 PC cables $18; Solar Radiation Sensor $199; Light Sensor Bracket $25; Light Sensor Level $30)

MIT Building 1 Weather Station

https://hobolink.com/p/7fada68f0ced39868cc265d13a801db2





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Climate Files

A Typical Meteorological Year (TMY) is defined as a set of real measured hourly values for dry temperature, for global, diffuse, and direct normal solar radiation, and for wind velocity. The data are in true sequence within each month. The most important input variables are:

Dry Bulb Temperature [°C]

Relative Humidity [%]

Direct & Diffuse Solar Radiation [W/m²]

Wind Speed & Direction [km/h]

Note:
- ❑ Many simulations find TMY not stringent enough to meaningfully test the performance of a building under extreme weather conditions such as heat waves.
- ❑ There is a new set of weather data for the US every 12 years. We are currently at TMY3.
- ❑ Weather data will change due to climate change.

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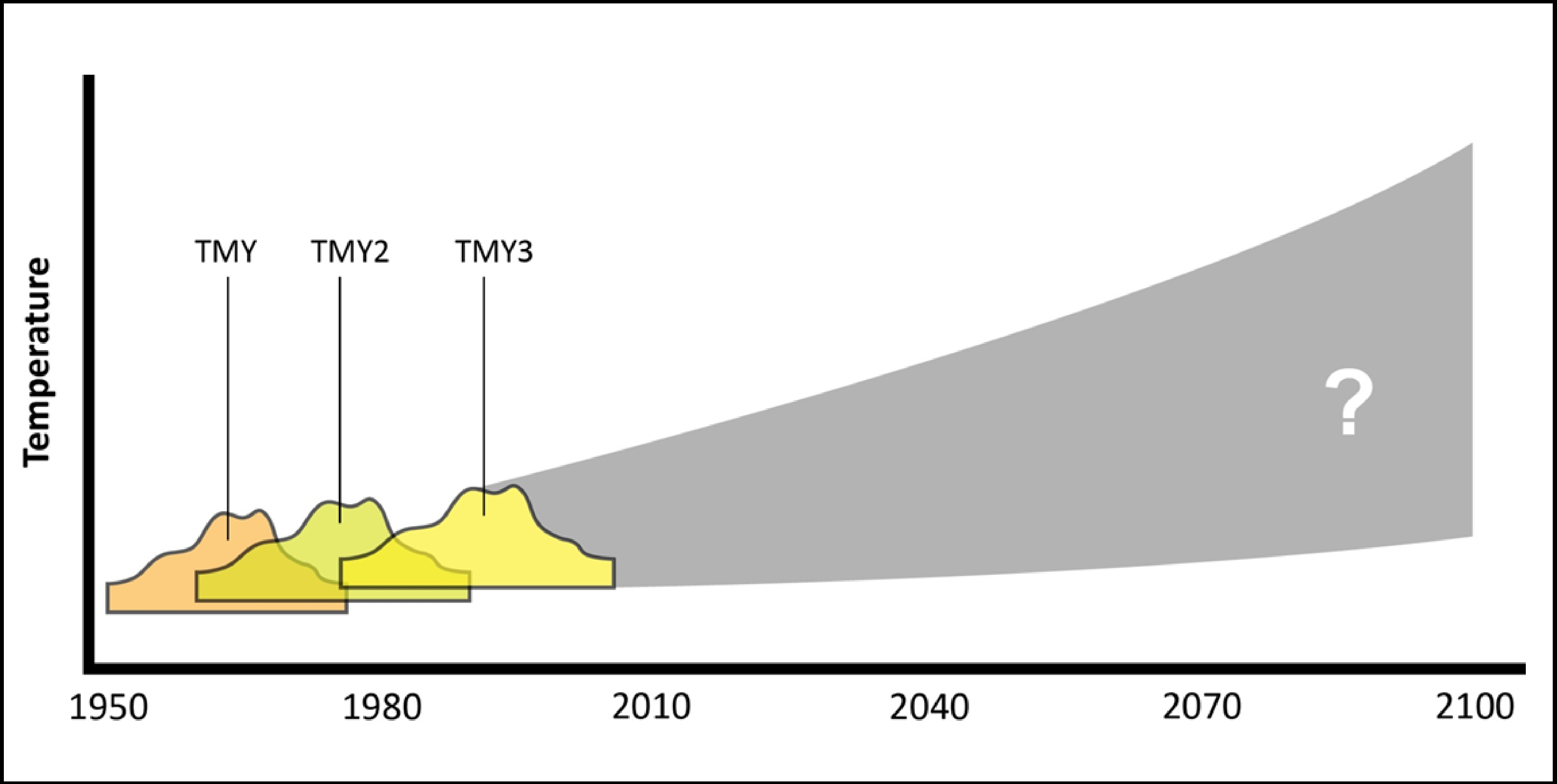
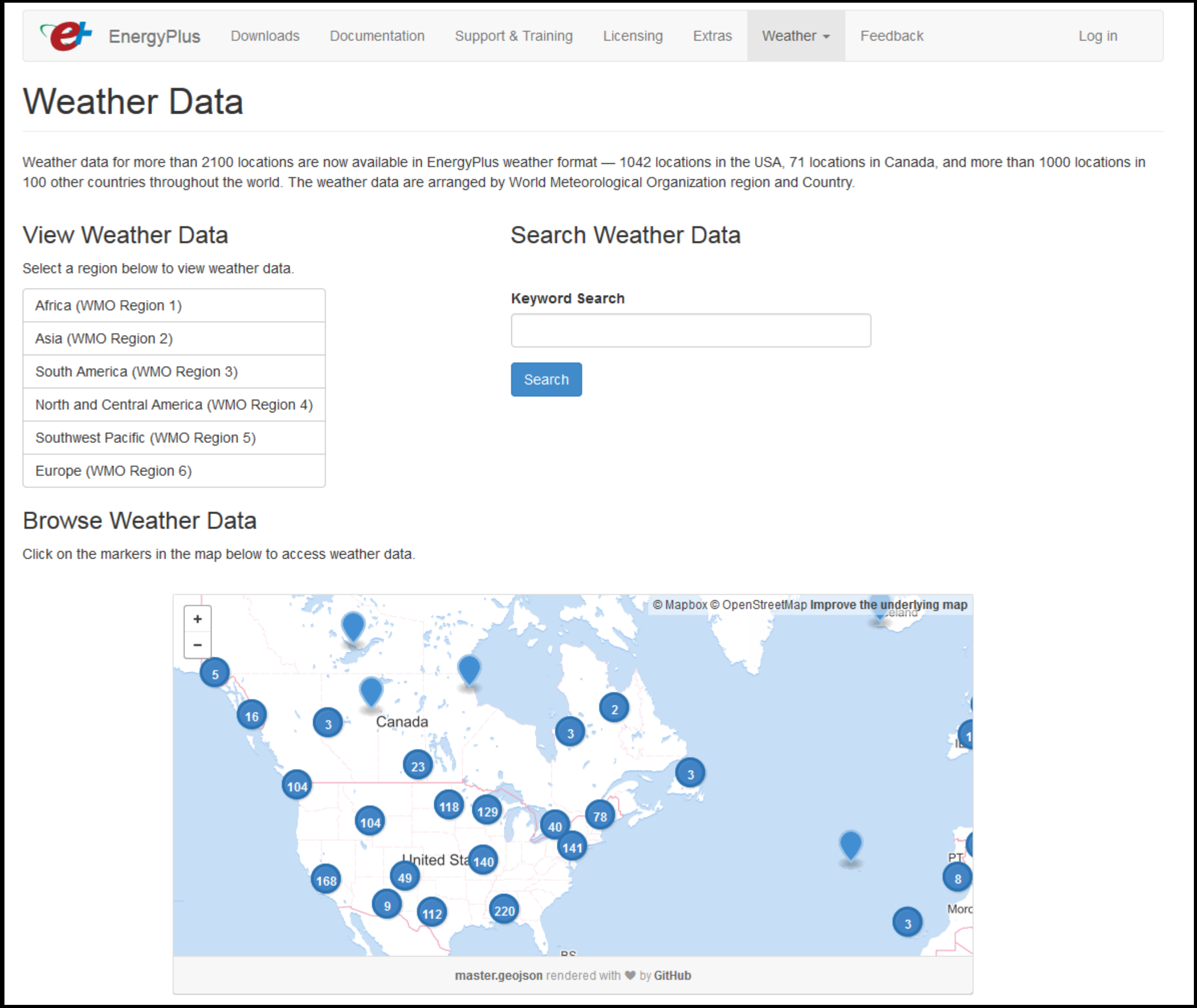
TMY, TMY2, TMY3,...



EnergyPlus Weather Data



- Google 'EnergyPlus weather data.'
- Import into Climate Consultant.

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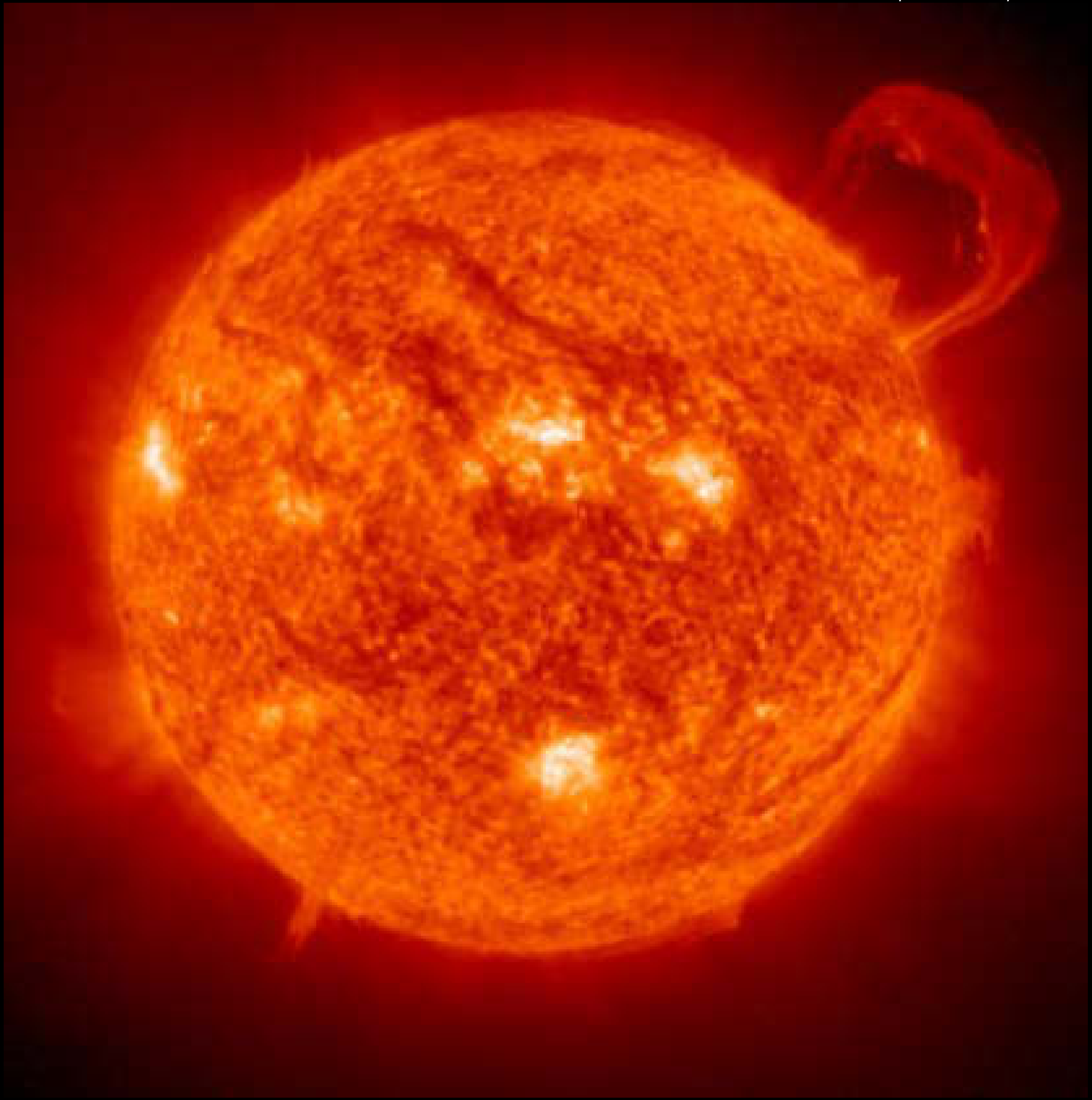
Solar Radiation

Our Sun

Public domain photo courtesy of NASA.



150 million km away; diameter of 1.4 million km; surface temperature of 5800 K

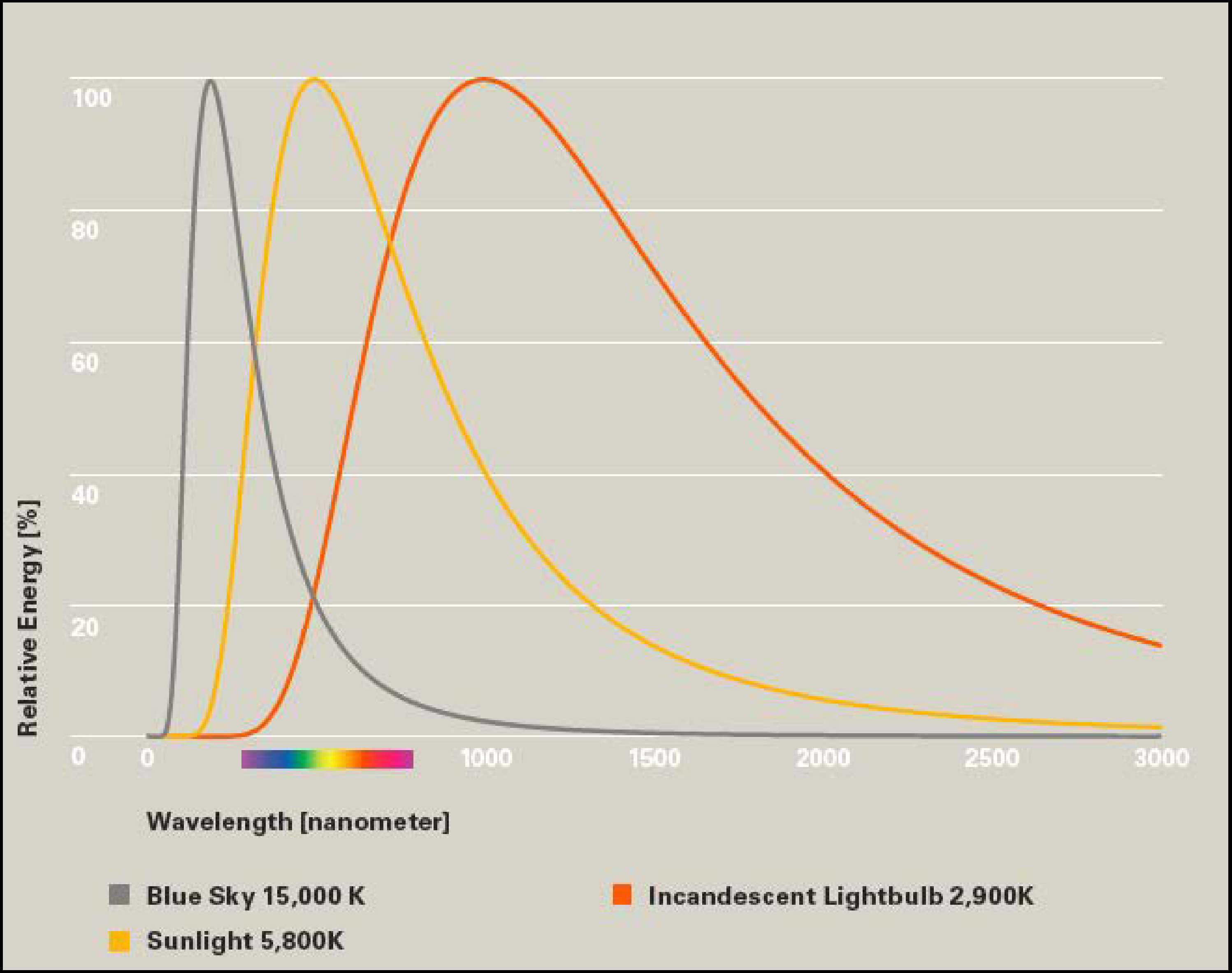
Direct Sunlight

Public domain image courtesy of DiamondTDesign on Flickr.

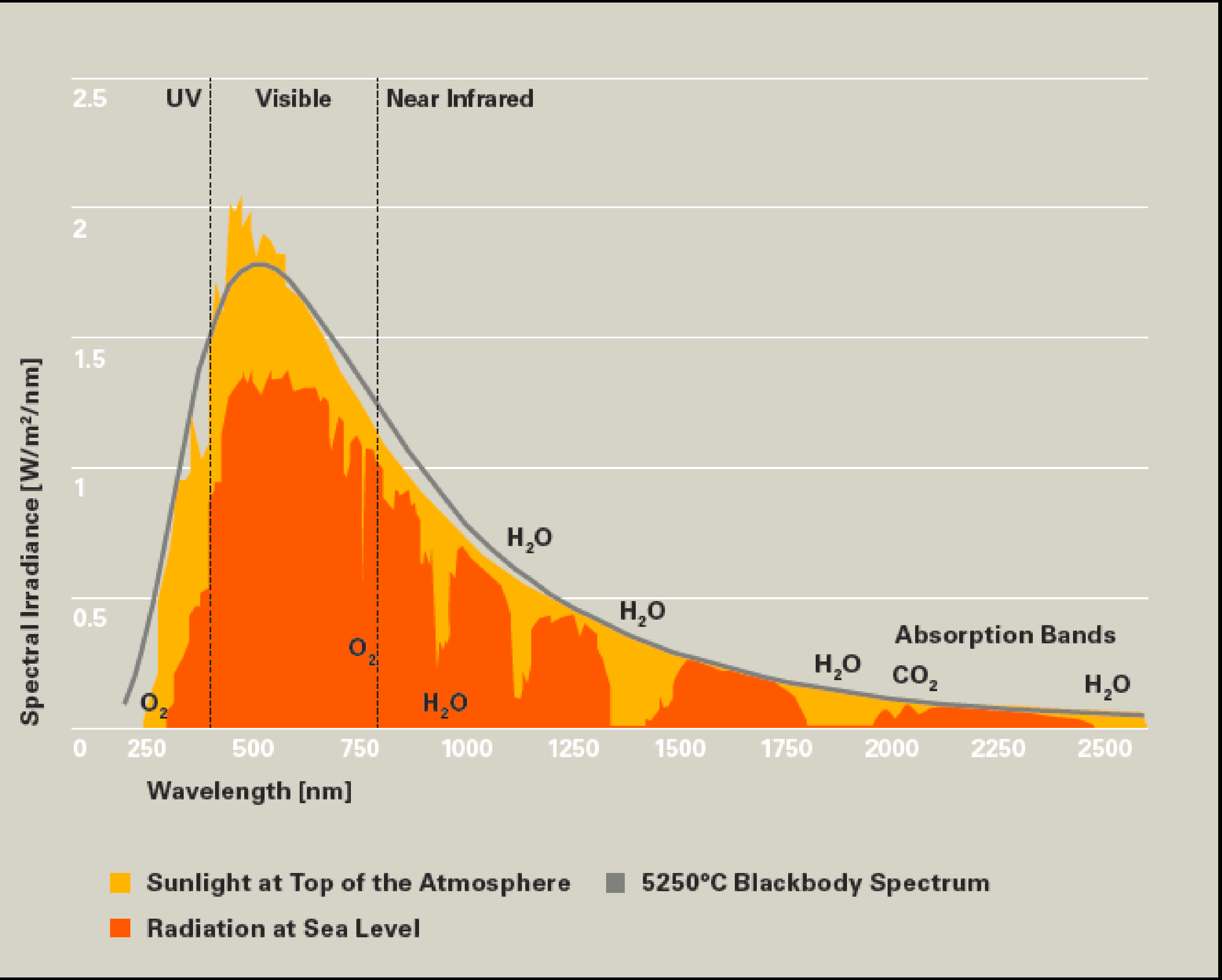
Solar Disk: 0.5 Degree Opening Angle (0.001% of hemisphere)

Circumsolar Region: 5 Degree

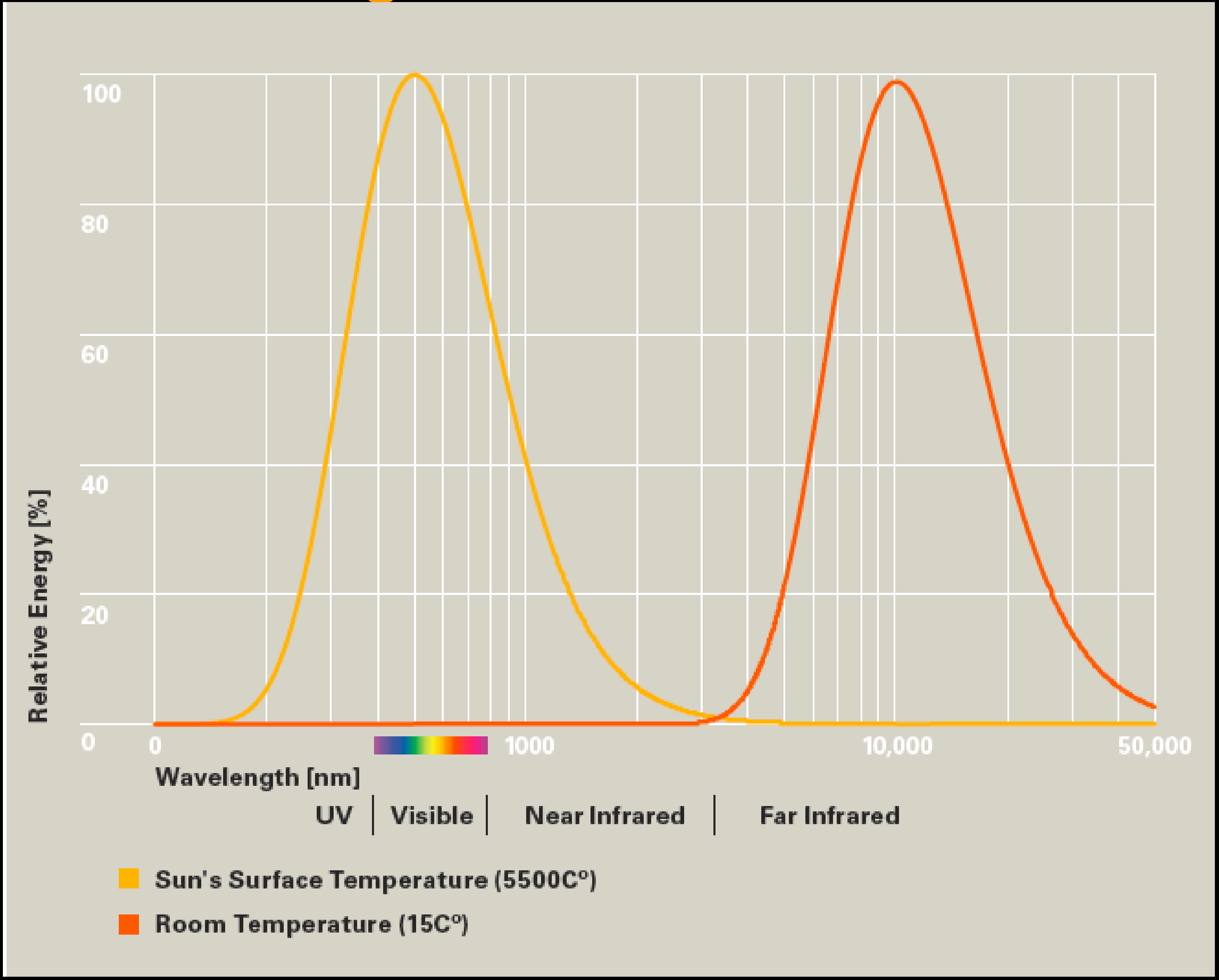
Black Body Spectra



Solar Spectrum



Four Wavelength Bands



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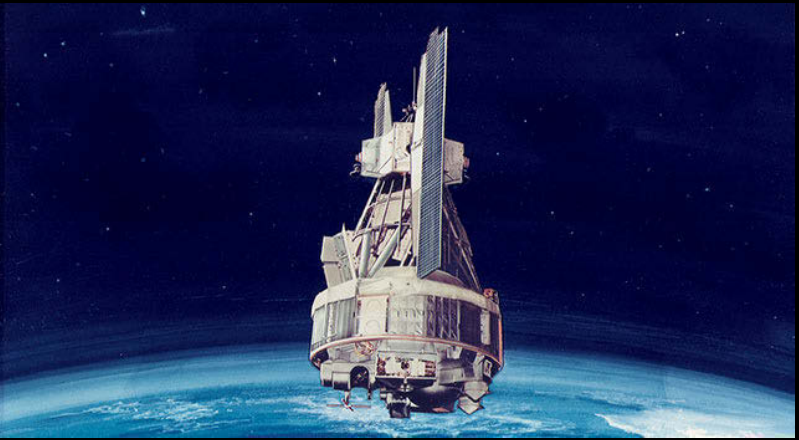
Solar Radiation in the Atmosphere

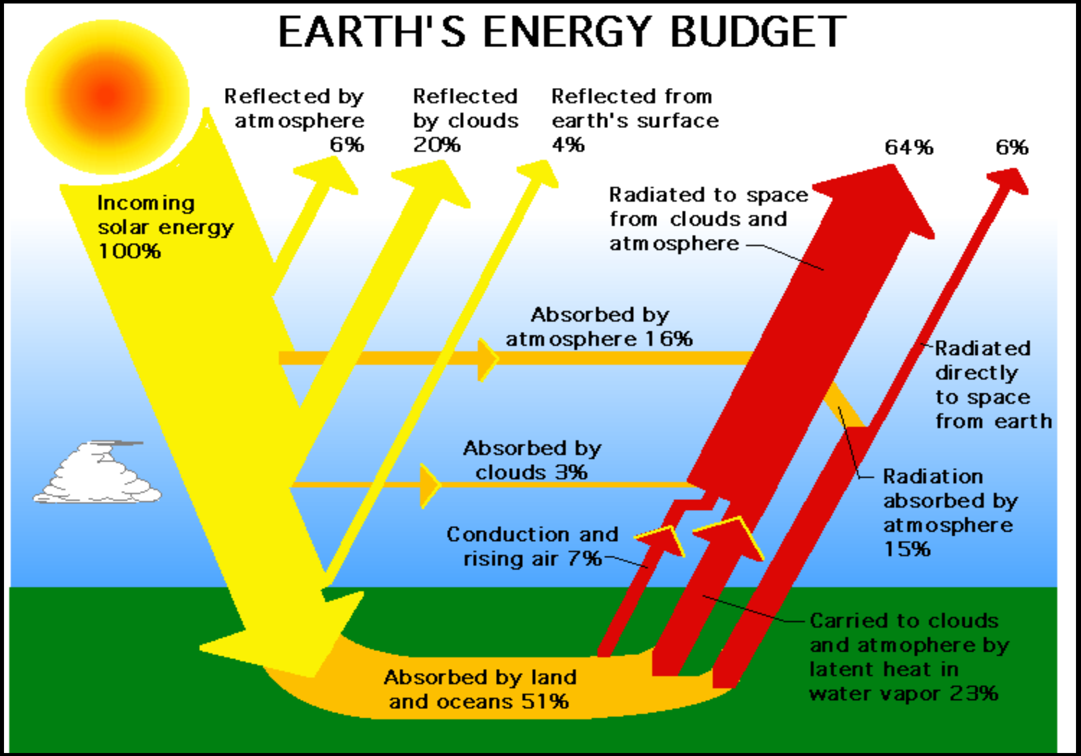
Solar Constant 1367 W/m^2



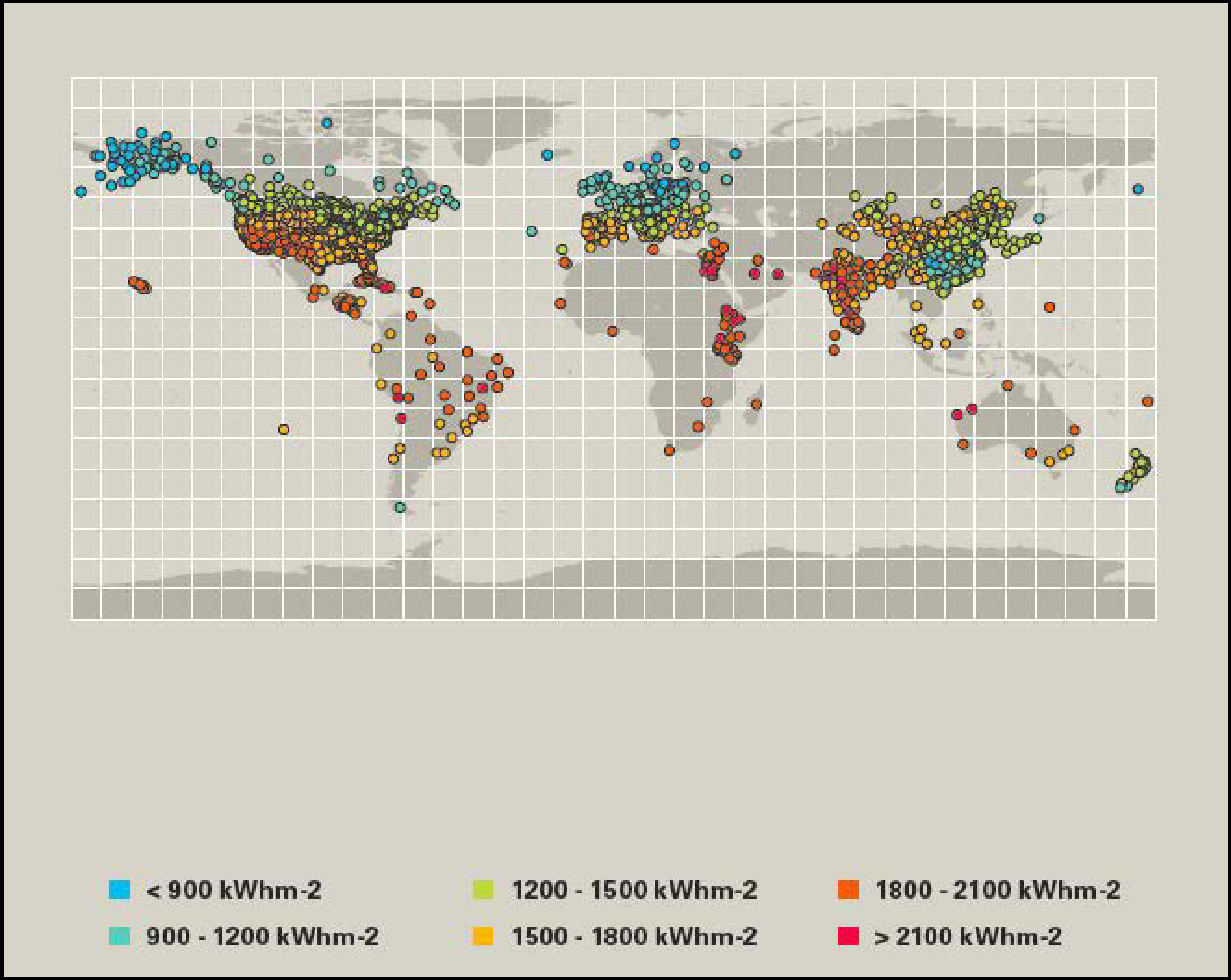
Top of Atmosphere

Public domain images courtesy of NASA.

Global Horizontal Radiation for Different Latitudes



Annual Solar Radiation



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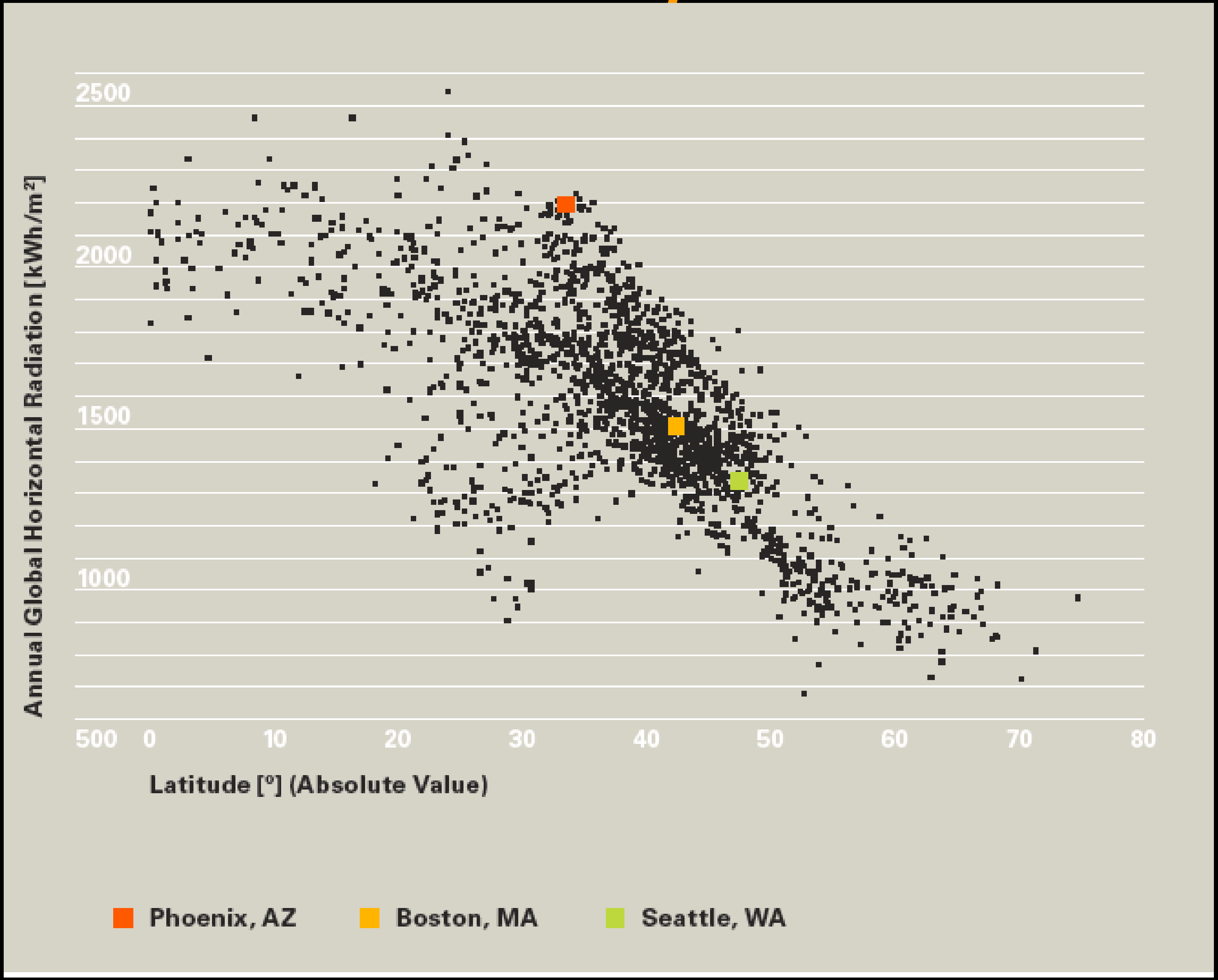
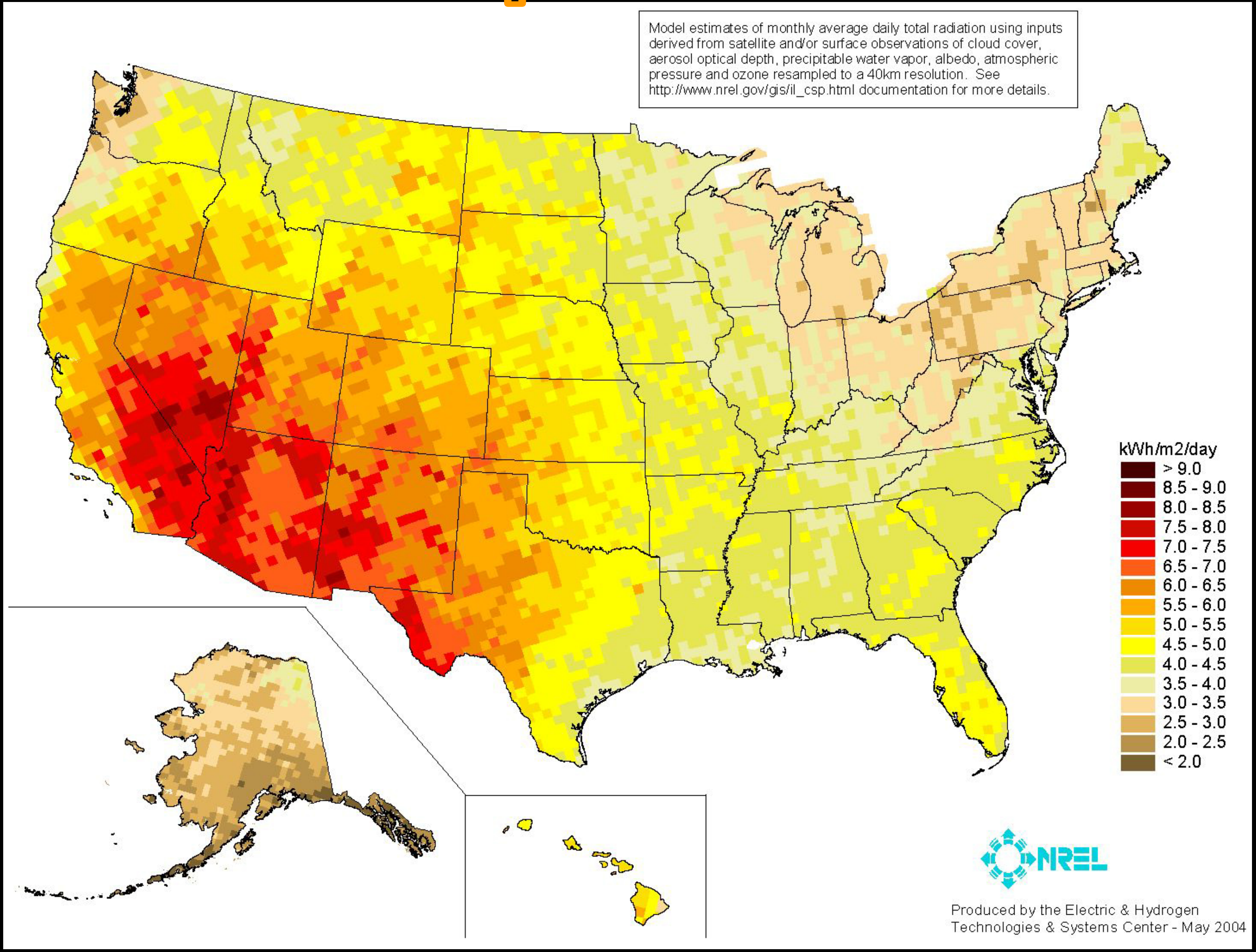
Annual Solar Radiation by Latitude

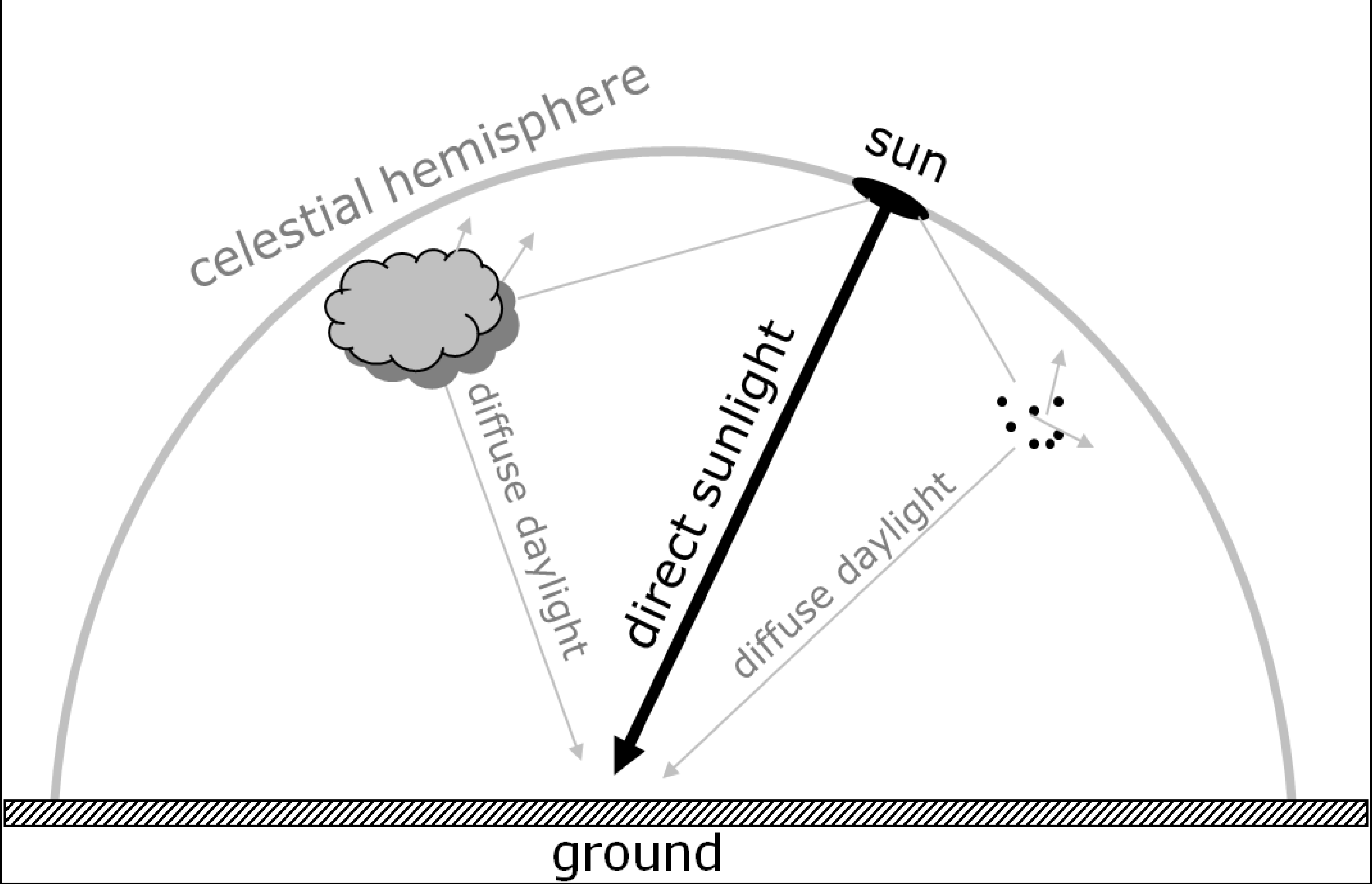


Solar Radiation throughout the US



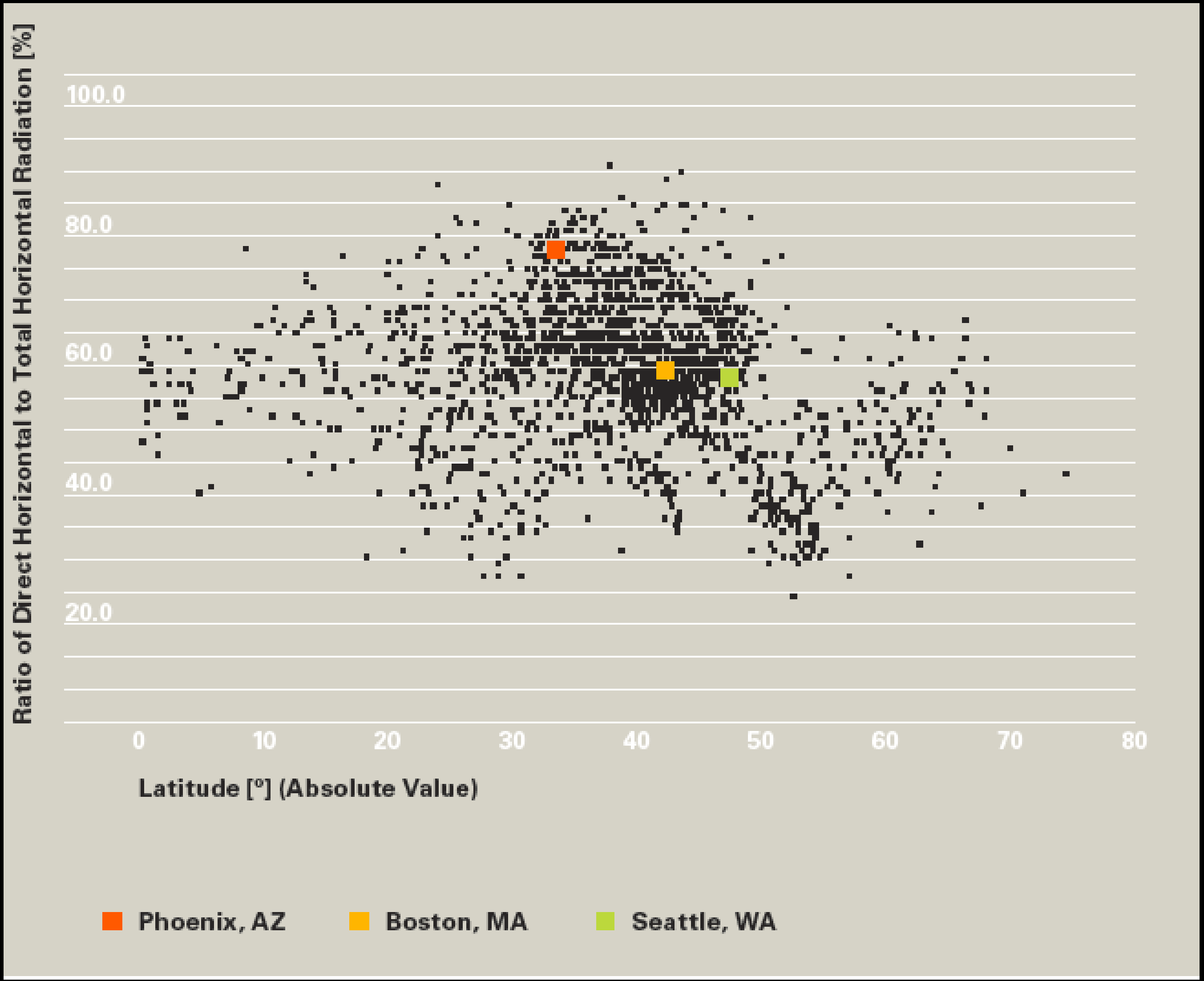
Public domain image courtesy of NREL.

Direct Sunlight and Diffuse Daylight



A considerable part of the sunlight that enters the Earth's atmosphere is scattered/reflected off clouds, aerosols, air molecules, and water vapor before it hits the Earth's surface. This part is responsible for the blue sky and is called **diffuse daylight**.

Ratio of Direct to Total Solar Radiation



- 50-70% of all solar radiation is direct.
- I.e., you always should know where the sun is.

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Radiation for Different Sky Types

100-400 W/m^2

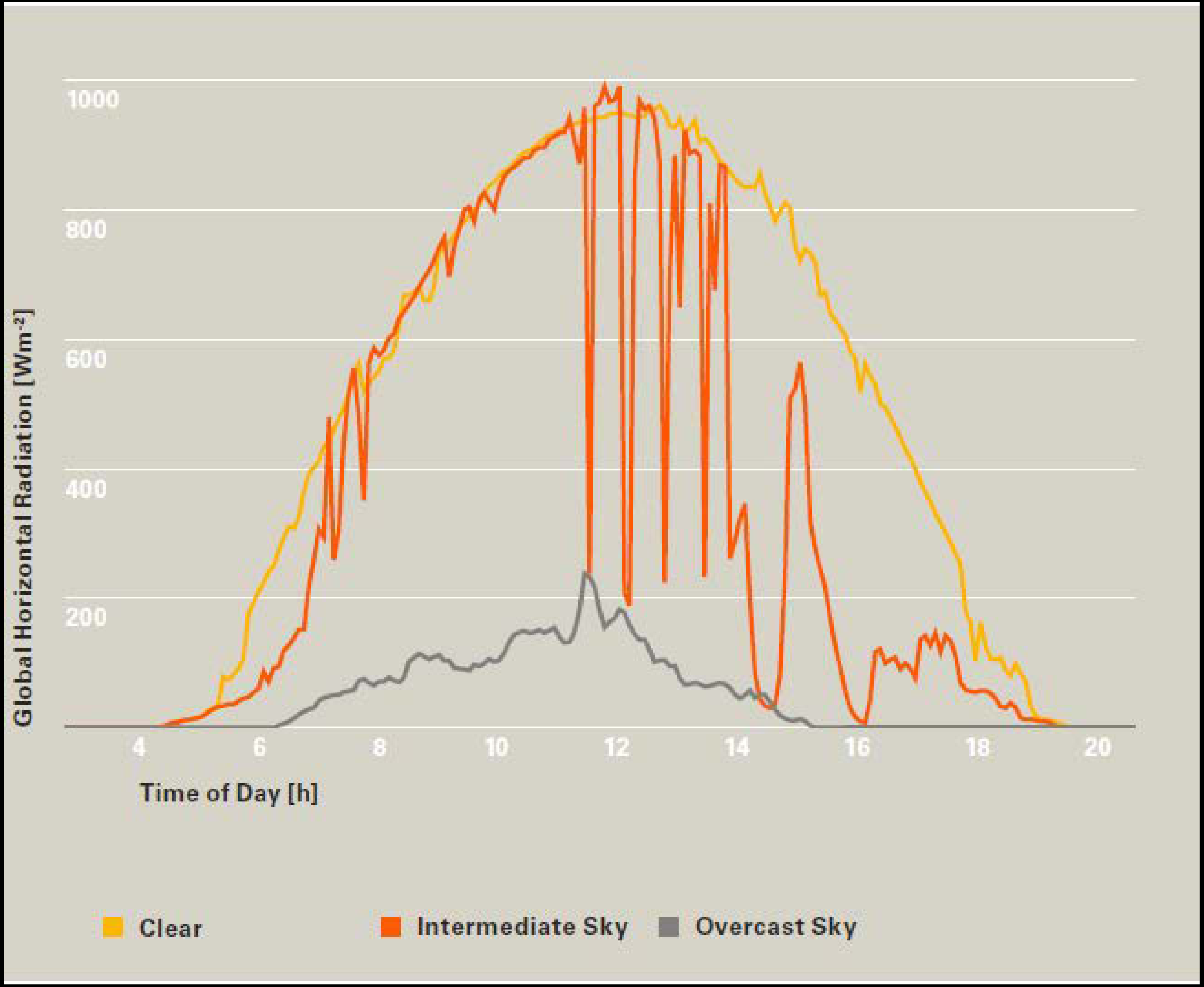
600-1000 W/m^2

Overcast Sky

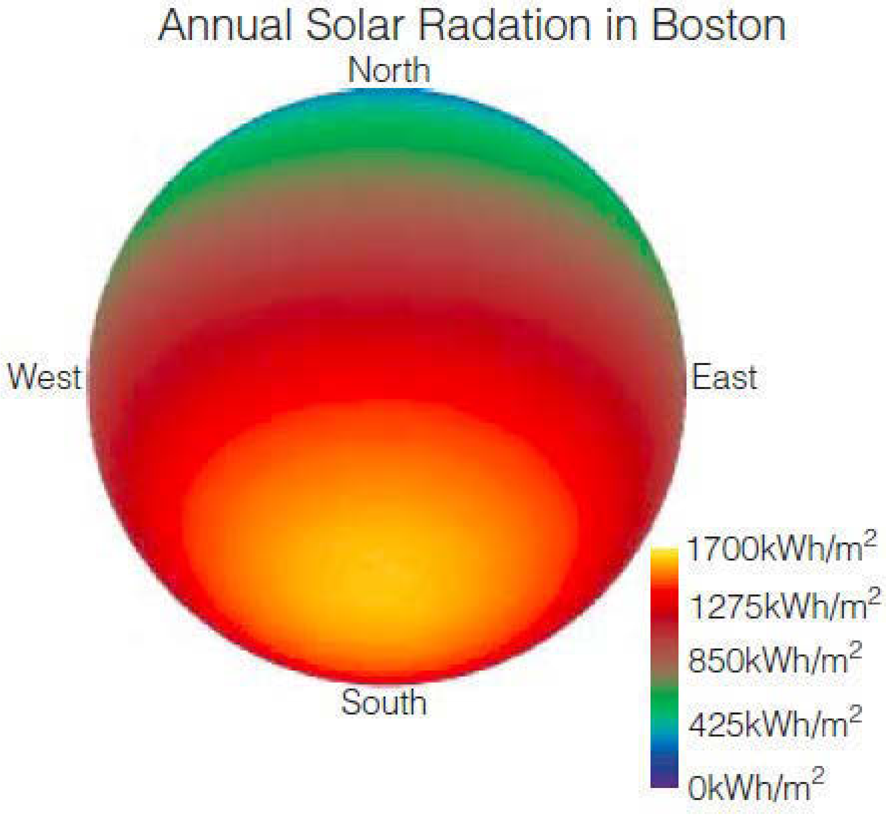
Partly Cloudy Sky

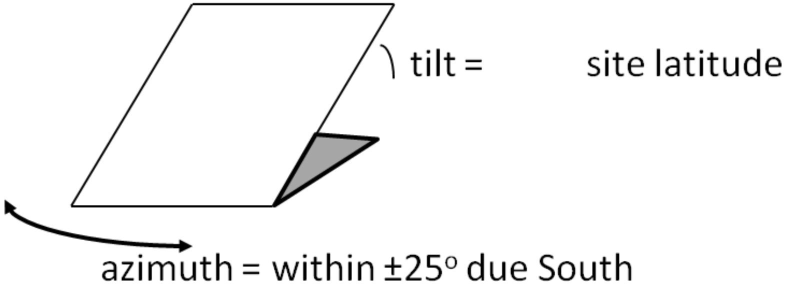
Clear Sky

Sky Conditions



Distribution of Radiation





Design Principle: Rule of Thumb for Solar Radiation

The maximum annual solar radiation generally falls onto a surface with a tilt angle that corresponds to the site's latitude and that is facing within ±25º due South.

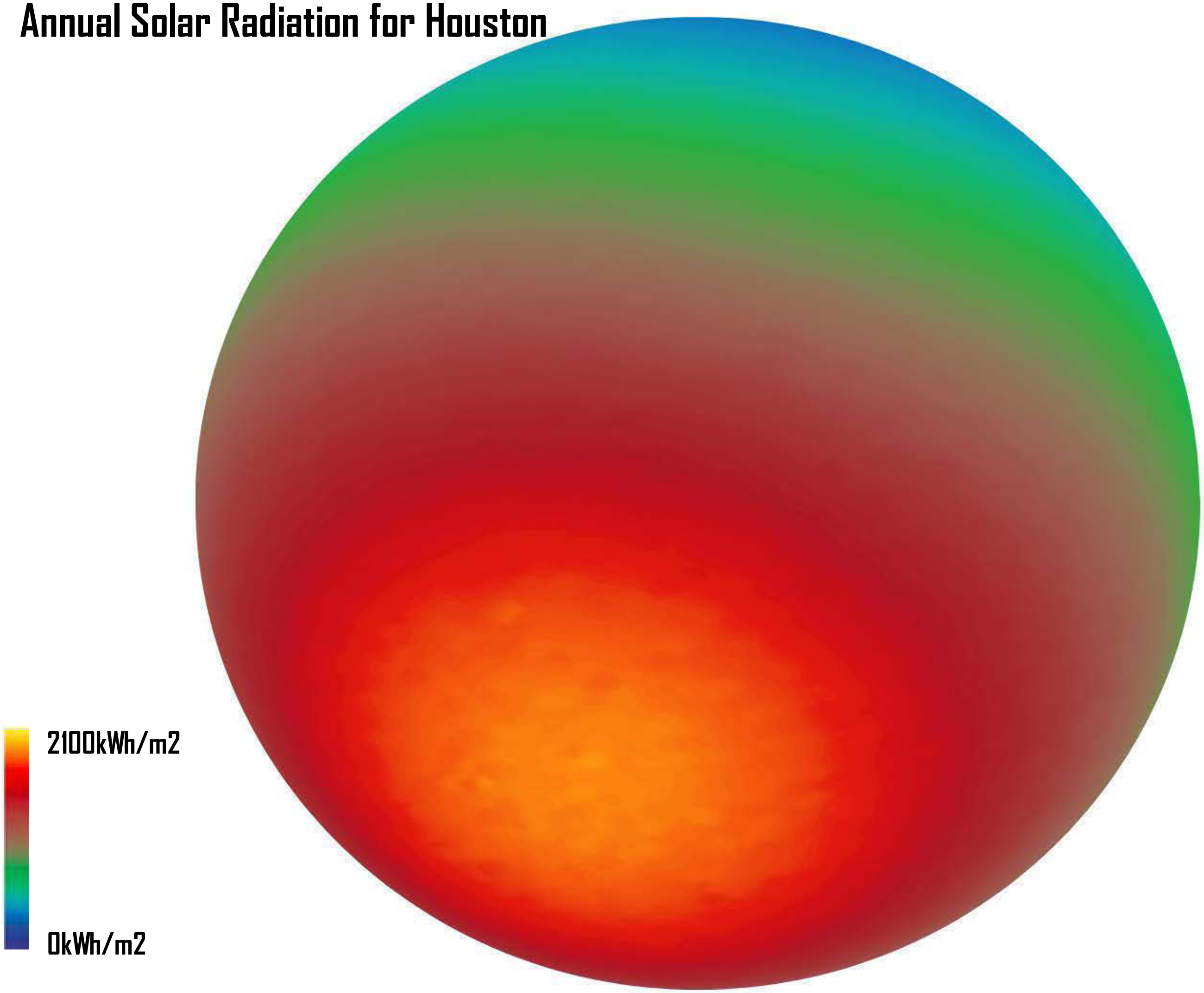
CLIMAPLUS

2100

Solar radiation

Maximum solar
Radiation [kWh/m2]

Annual Solar Radiation for Houston



Source: Tool under development by Alpha Arsano

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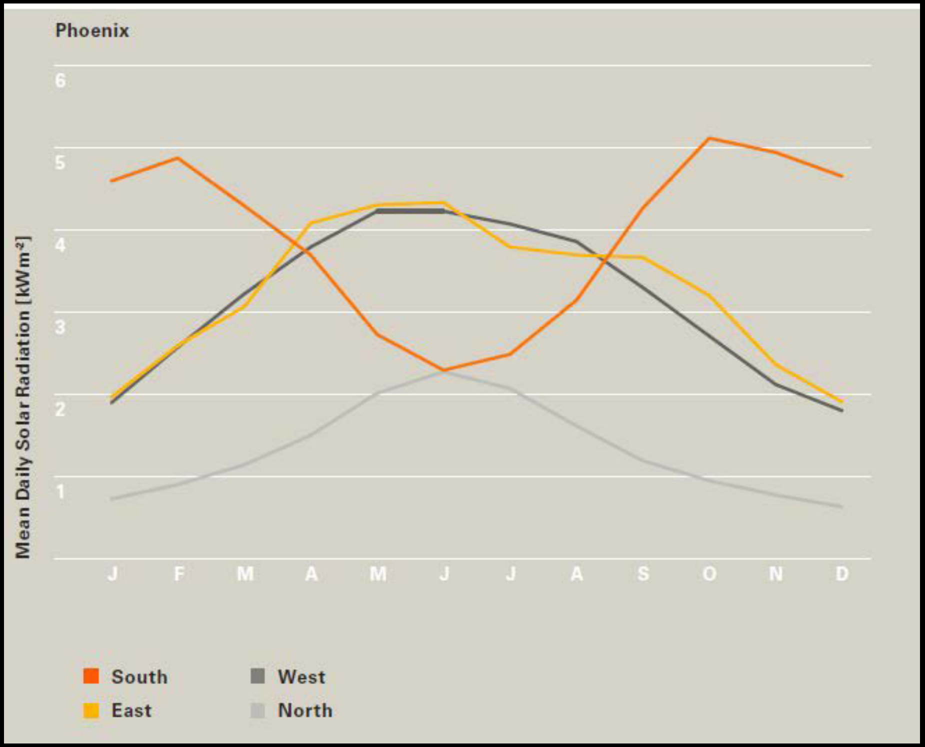
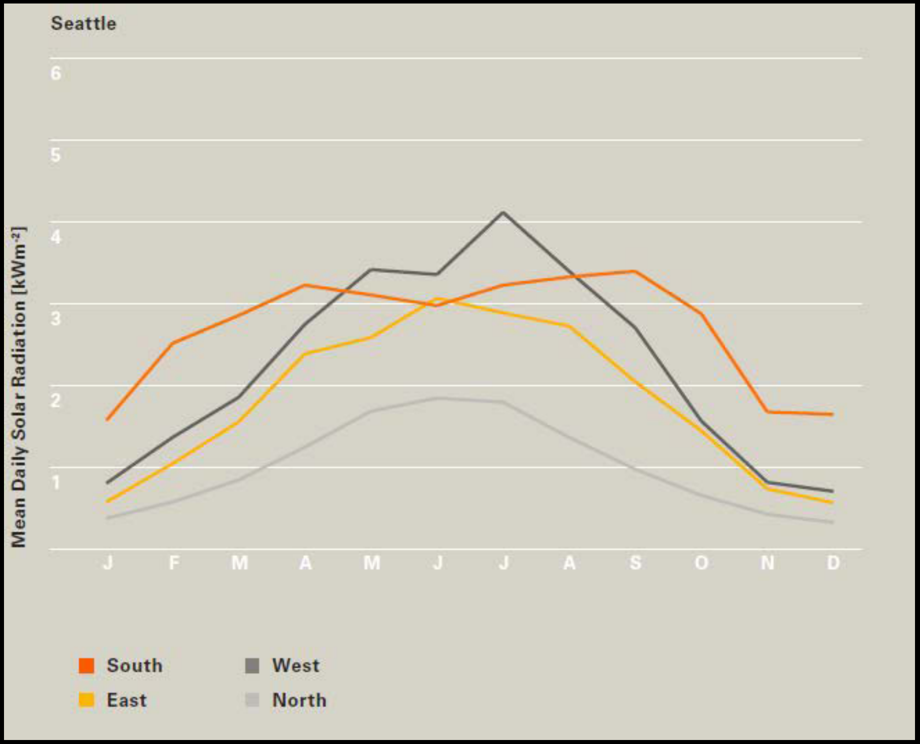
Daily Radiation on Surfaces





Southward orientation is less beneficial in Seattle than in Arizona.

Daily Radiation for Boston

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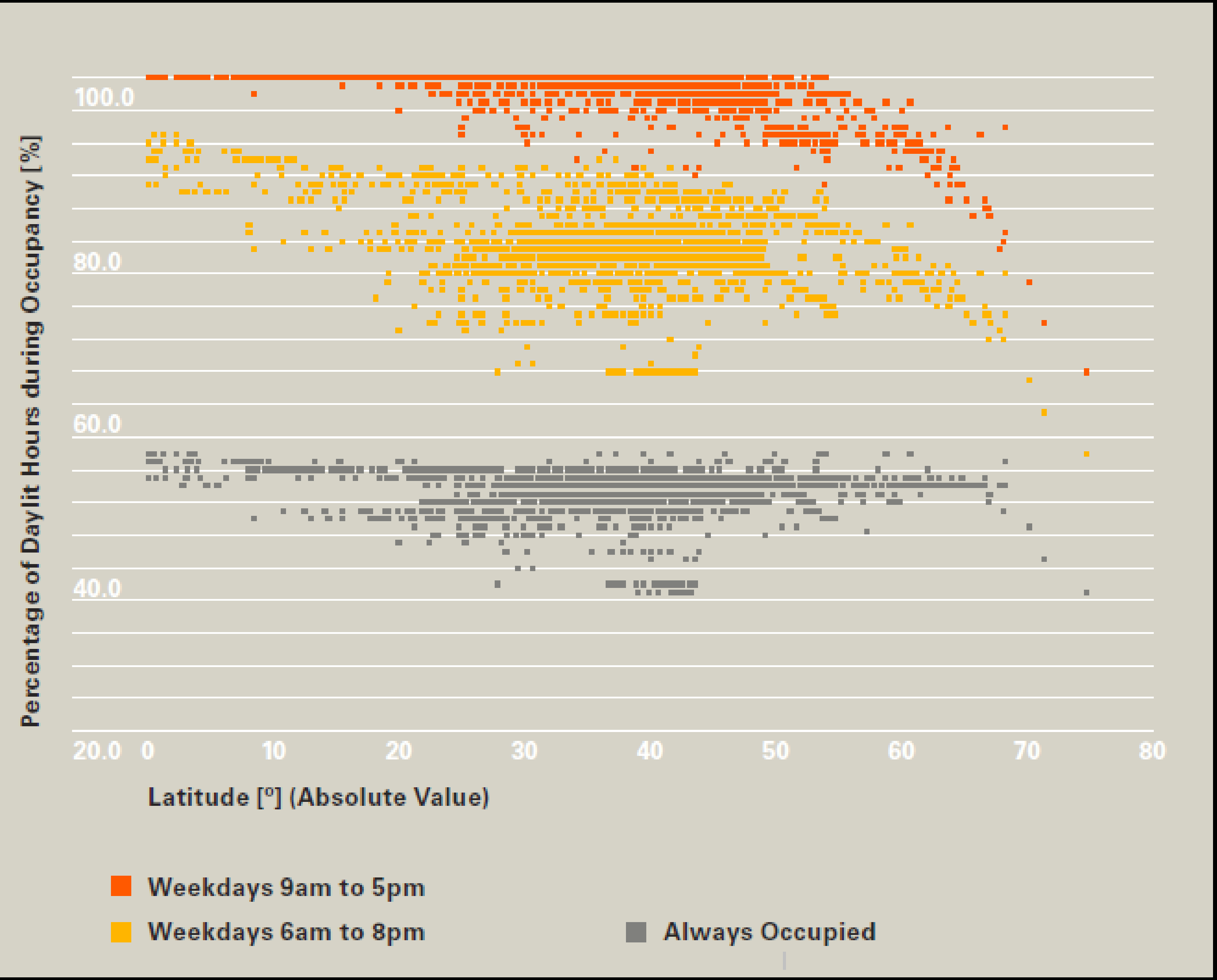
Percentage of Outside Daylit Hours During Occupancy



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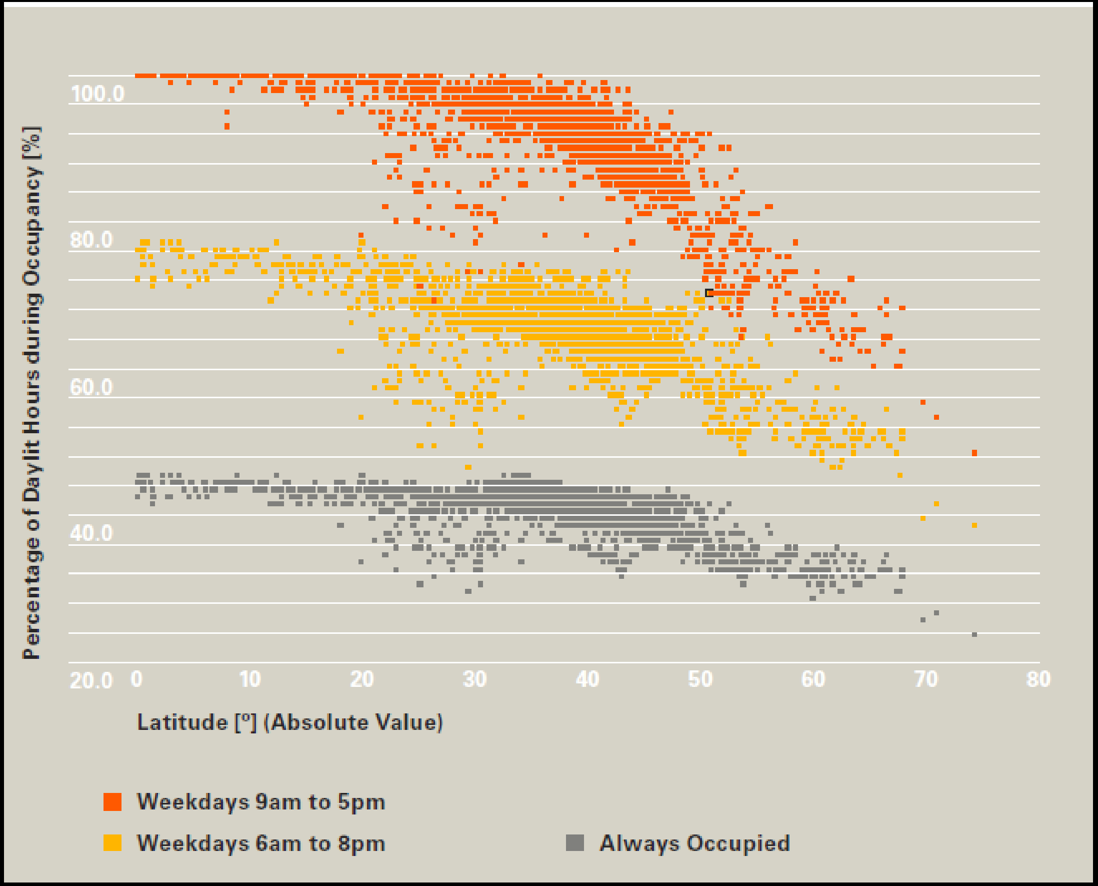
Percentage of Inside Daylit Hours During Occupancy



- For latitudes below 50º there is also the potential to daylight interior spaces for 80% of core commercial hours. With 93% of the world's population living at latitudes below 50º, daylighting can be considered to be a global solution for lighting buildings.

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Climate Data – Solar Radiation

Dry Bulb Temperature [°C]

Relative Humidity [%]

Direct Solar Radiation [W/m²]

Diffuse Horizontal Solar Radiation [W/m²]

Cloud Cover [%]

Wind speed [km/h]

Wind direction [Degree]

Rainfall [mm]

Measuring Global Solar Radiation

Image of pyranometers and photometers removed due to copyright restrictions.

Measuring Diffuse Solar Radiation

Shadow band pyranometer

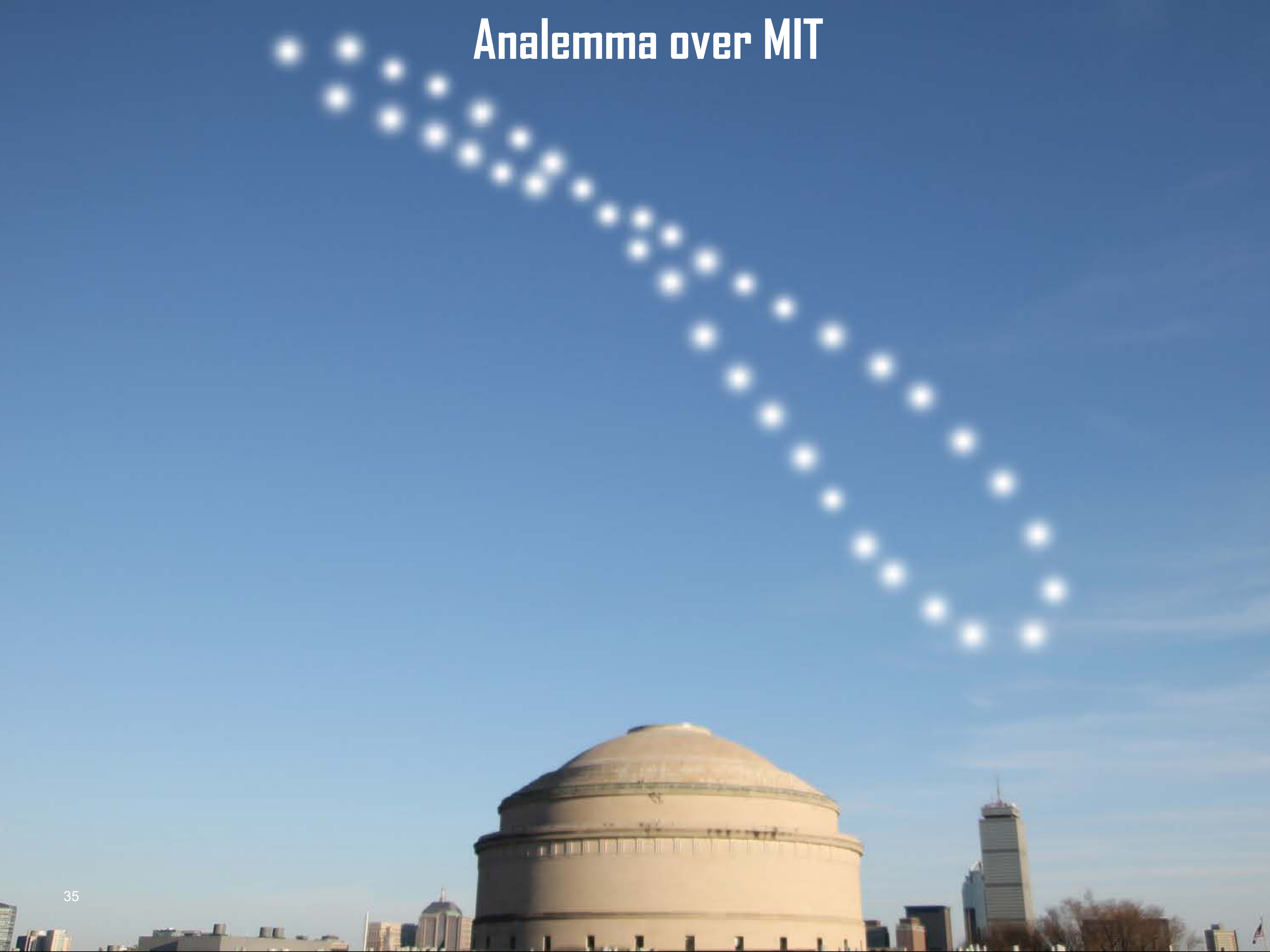
Measuring Direct Solar Radiation

Image of radiometers installed on an automatic
solar tracker removed due to copyright restrictions.

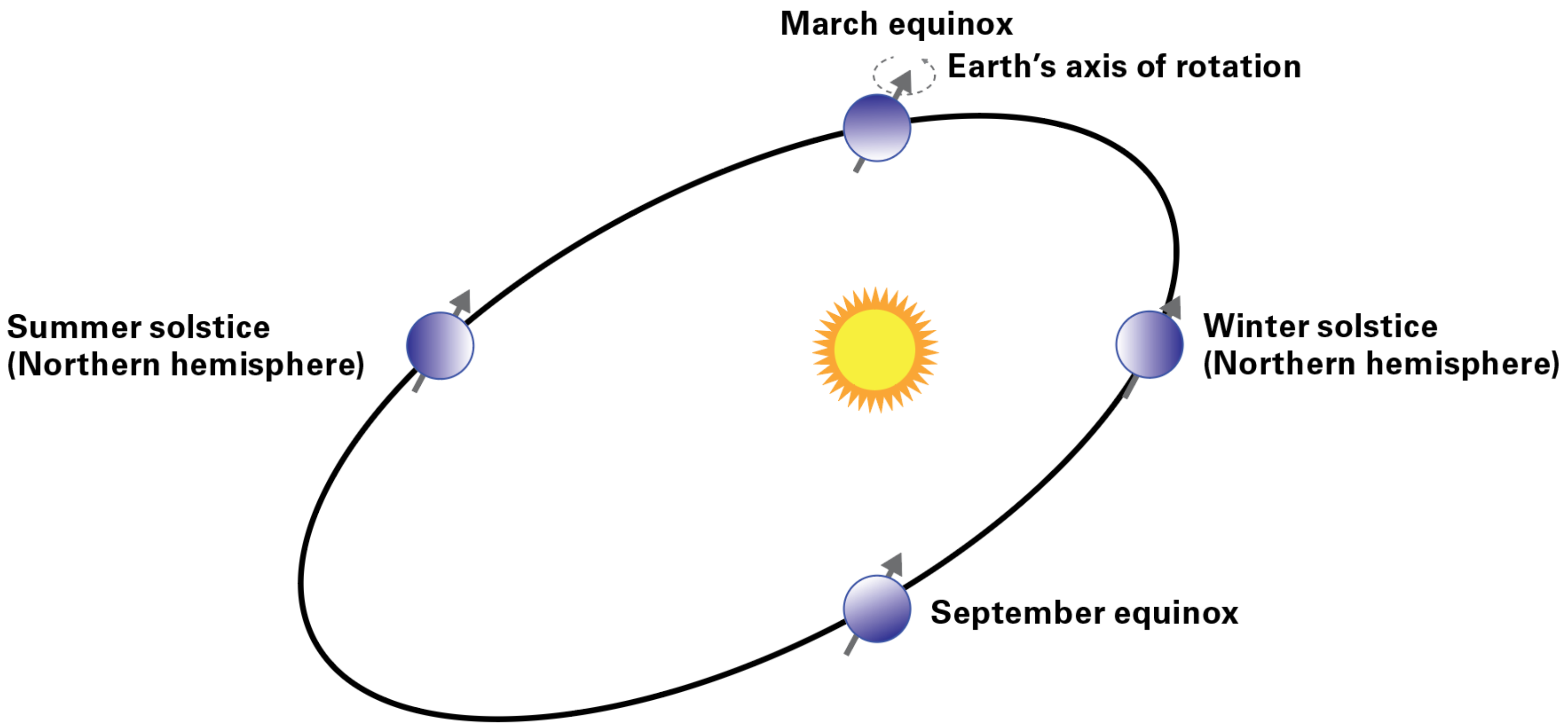
Tracking Pyranometer on the roof of the Fraunhofer ISE
(Photo courtesy of Amaia Puras. Used with permission.)

Where is the sun?

Analemma over MIT

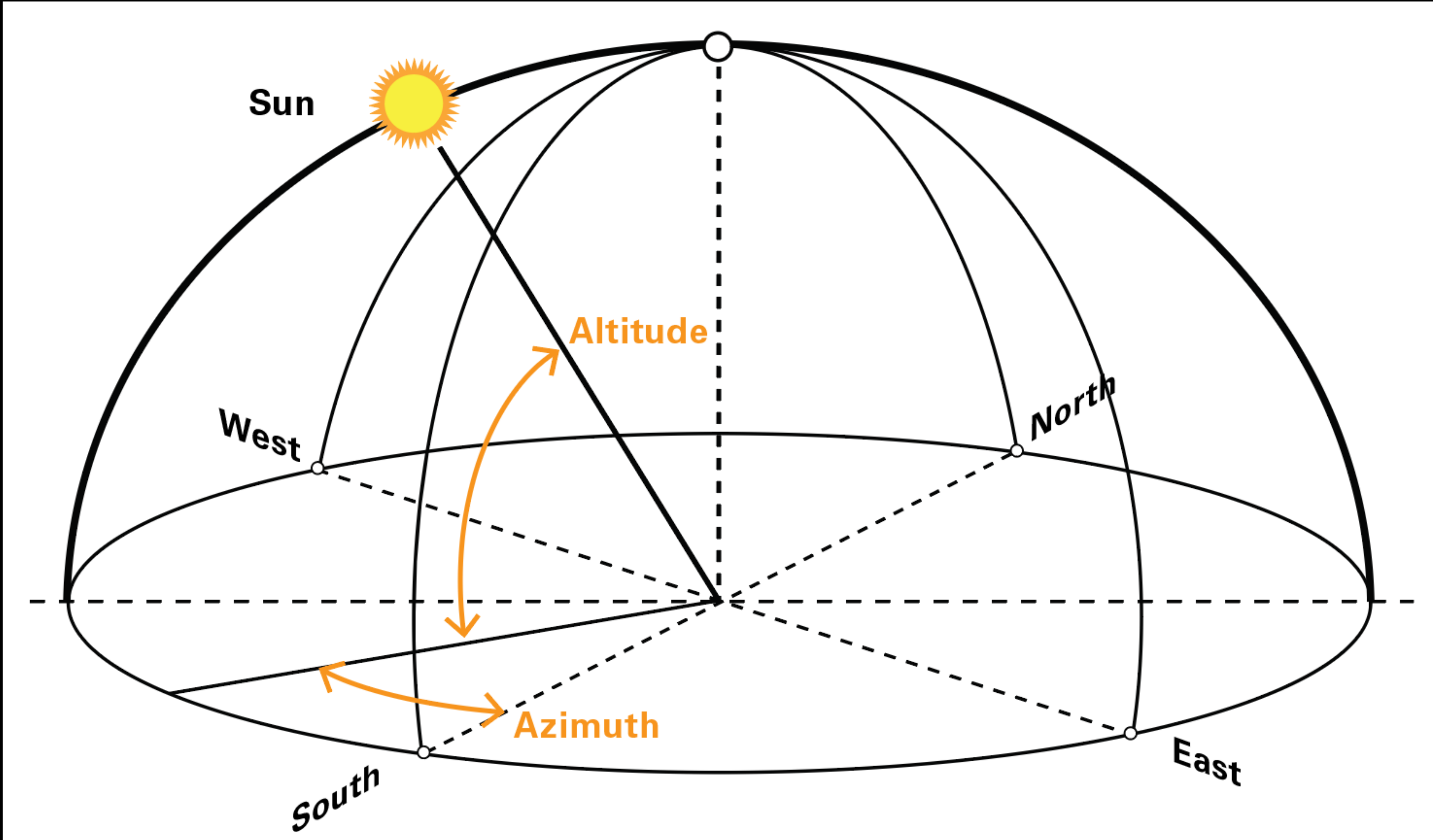


Earth's Orbit around the Sun



- Elliptical path; declination = 23.45°

Local Solar Coordinate System

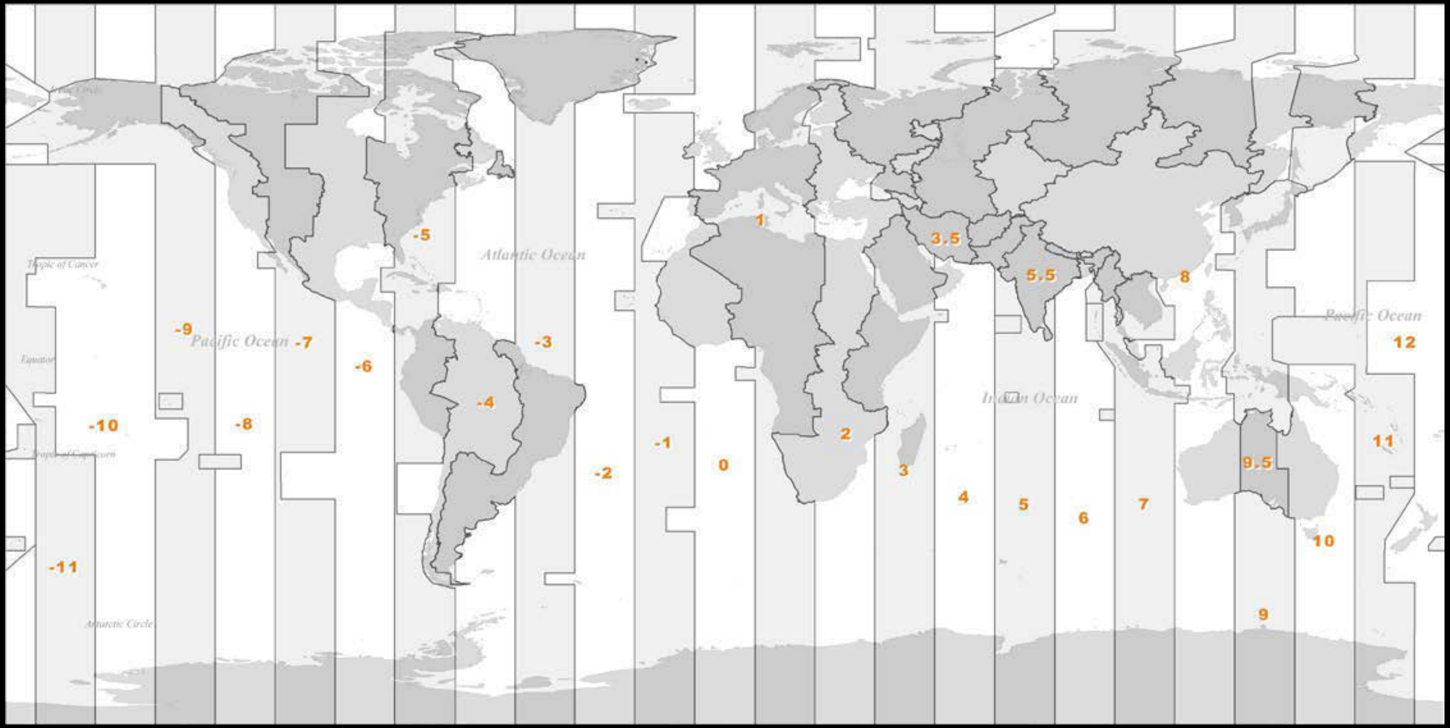


$$Altitude = \sin^{-1}\left(\sin(Latitude)\sin(Dec) + \cos(Latitude)\cos(Dec)\cos\left(\frac{ST}{24}\right)\right)$$

What time is it?

In our daily life we commonly refer to our location's standard local time.

- Standard times are synchronized with the times of all other locations within the same time zone.
- Greenwich Mean Time (GMT) is the local time at Greenwich, England.
- In Boston we are five time zones west of Greenwich (GMT-5).
- Time zones divide the earth into 24 strips that are each about 15° wide even though time zones also follow political and geographic boundaries.



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Why a standard time?

- ❑ The introduction of a standard time facilitates long distance travel and communication.

- ❑ A disadvantage of using standard time is that our experience of time is not directly linked to the position of the sun any more.

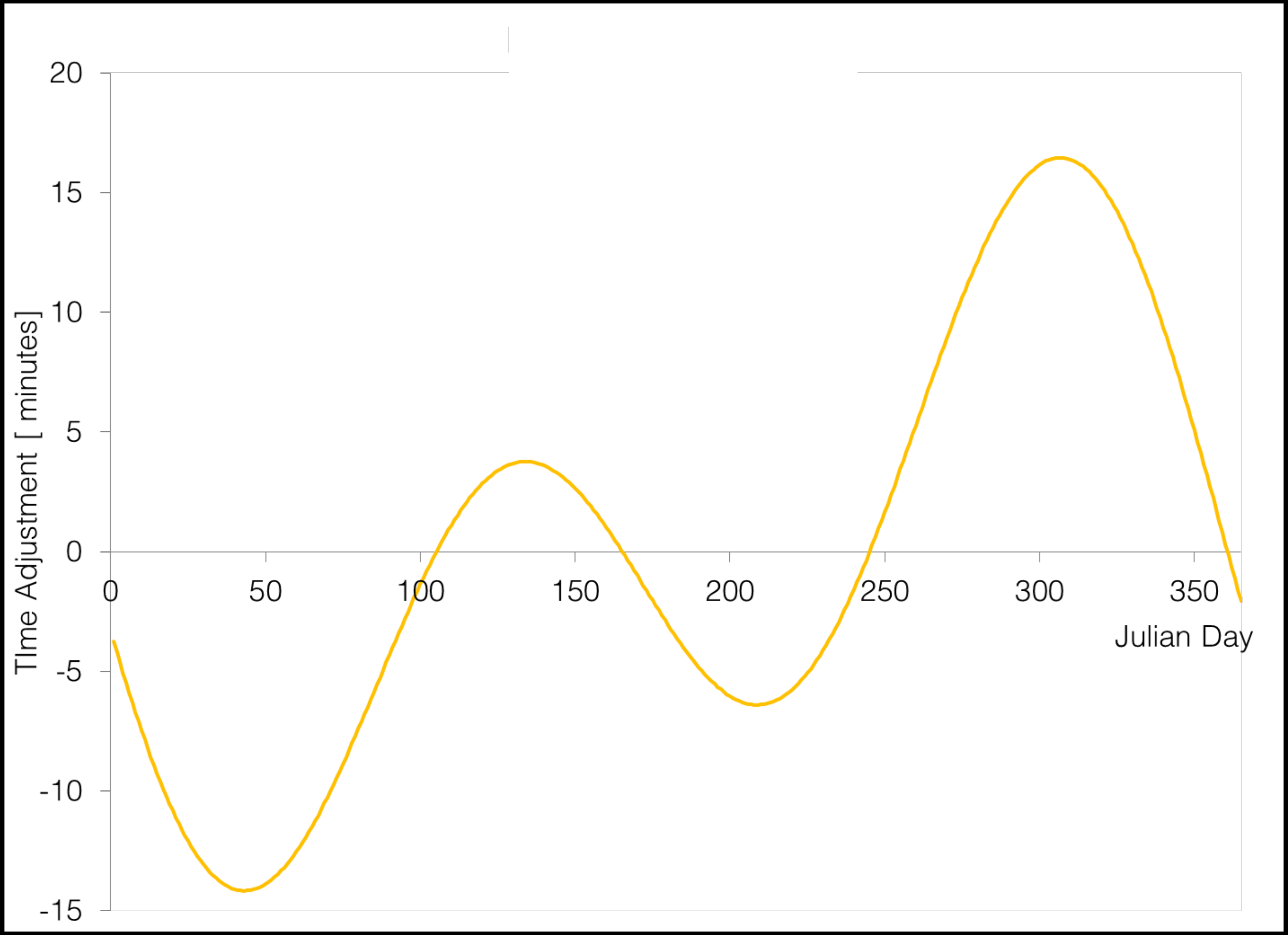
- ❑ Before the introduction of standard time in the US in 1883, different versions of solar time were used instead.

- ❑ In true solar time it is noon exactly when the sun is located to the south (azimuth angle equals zero).

- ❑ Solar time Boston is about 11 minutes ahead of solar time New York since both cities have different longitudes.

Equation of Time

- A second difference between standard time and solar time is caused by the elliptical movements between sun and earth. This time difference is called the 'equation of time'.



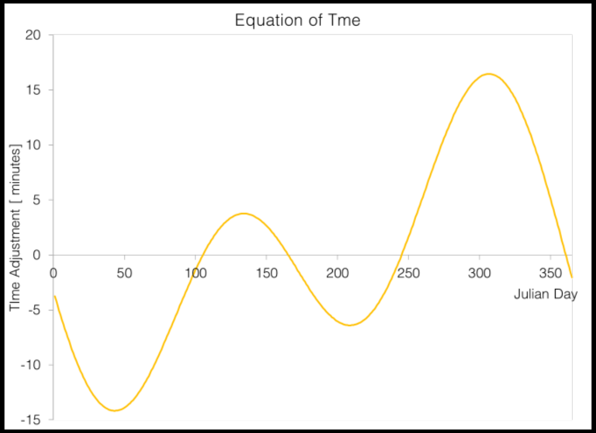
From Local to Solar Time

Solar Time = Standard Local Time

$+ 4x(Longitude_{standard} – Longitude_{observer})$

+ equation of time

Standard Local Time



Equation of Time

Example

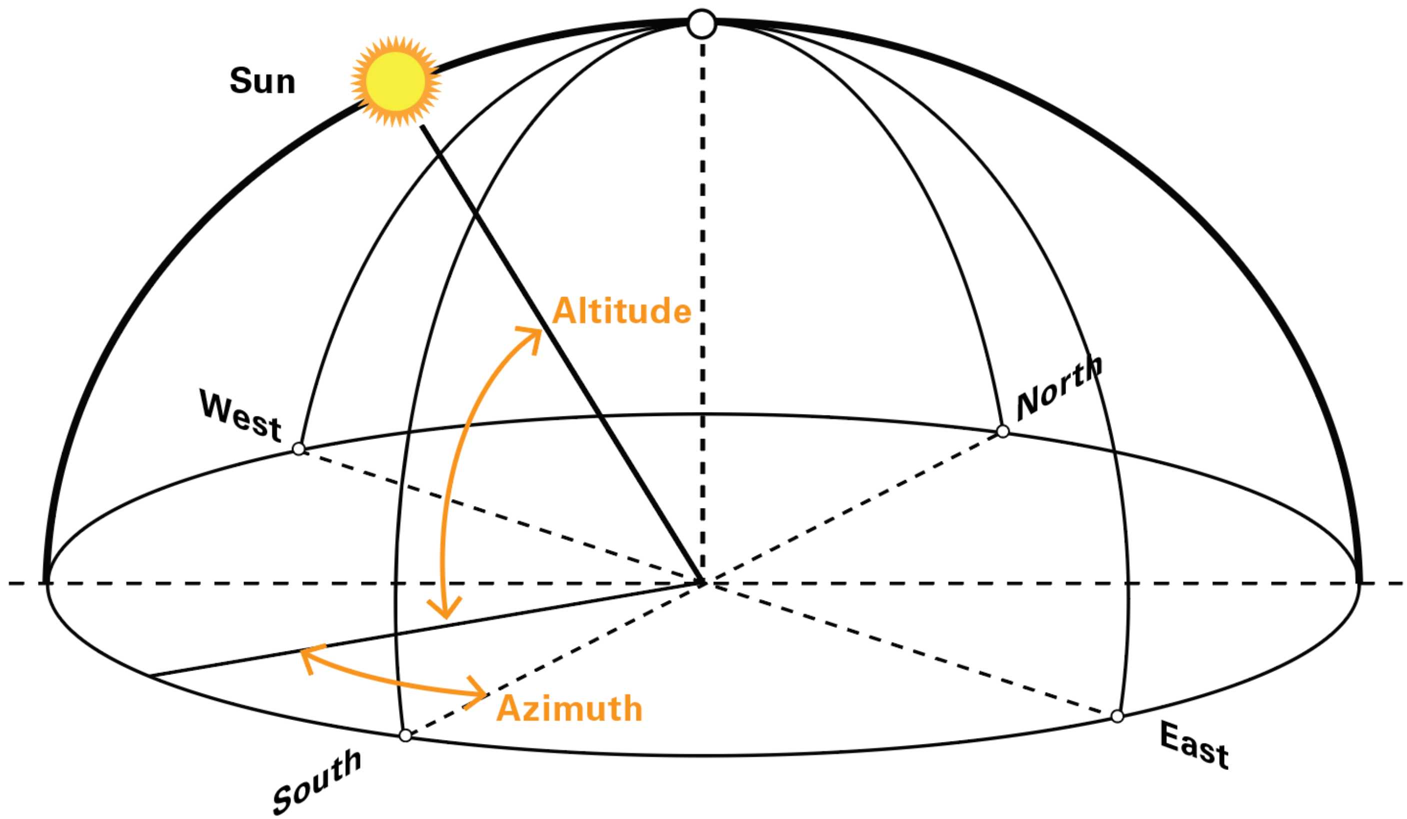
Standard Time = Feb 29 2012 at 10.04 AM in Boston

$4 \times (Longitude_{standard} – Longitude_{observer}) = 4 \times (75^{o} W - 71.02^{o} W) = 15.9\ min$

equation of time (Feb 29) = -12.5 min

Solar Time = 10 h 4 min -12.54+15.92 min = 10 h 7.4 min = 10.12333

Sun Position



$$Azimuth = \tan^{-1}\left(\frac{\cos(d)\sin(ST/24)}{-\cos(Lat)\sin(d) - \sin(Lat)\cos(d)\cos(ST/24)}\right) \quad \textbf{Equ 6-3}$$

$$Altitude = \sin^{-1}\left(\sin(Lat)\sin(d) - \cos(Lat)\cos(d)\cos(ST/24)\right) \quad \textbf{Equ 6-4}$$

where d = declination=23.45°; ST = solar time in decimal hours; Lat = site's latitude in degrees.

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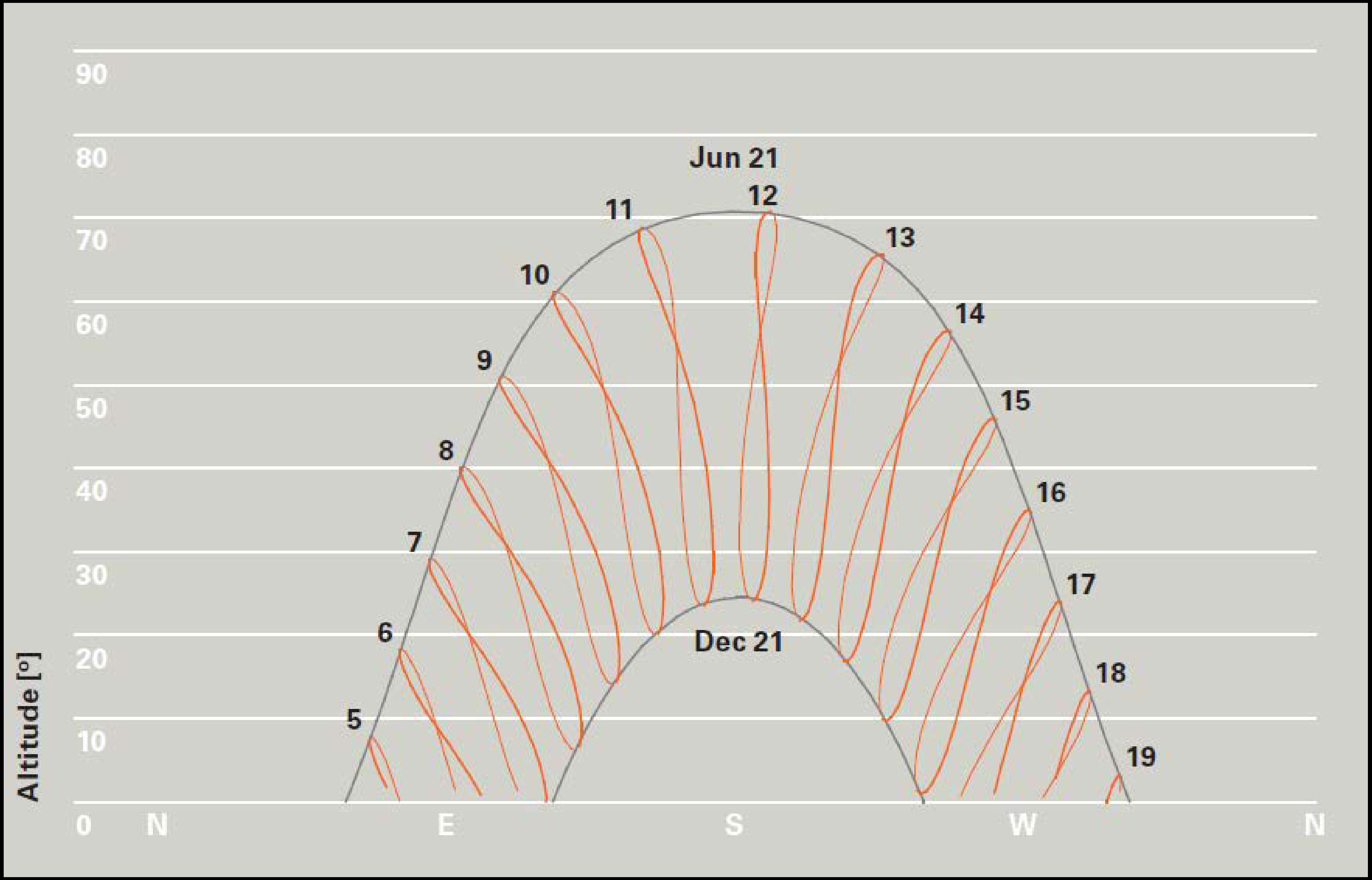
Sun Path Diagram

Excel Spreadsheet: http://mit.edu/sustainabledesignlab/teaching_resources.html >> Climate File Analyzer



- *Solar altitude range at noon = 90° – latitude ± 23.45°*
- *Example Cambridge (42.4° N): 90° – 42.4° ± 23.45° 24° to 70°*

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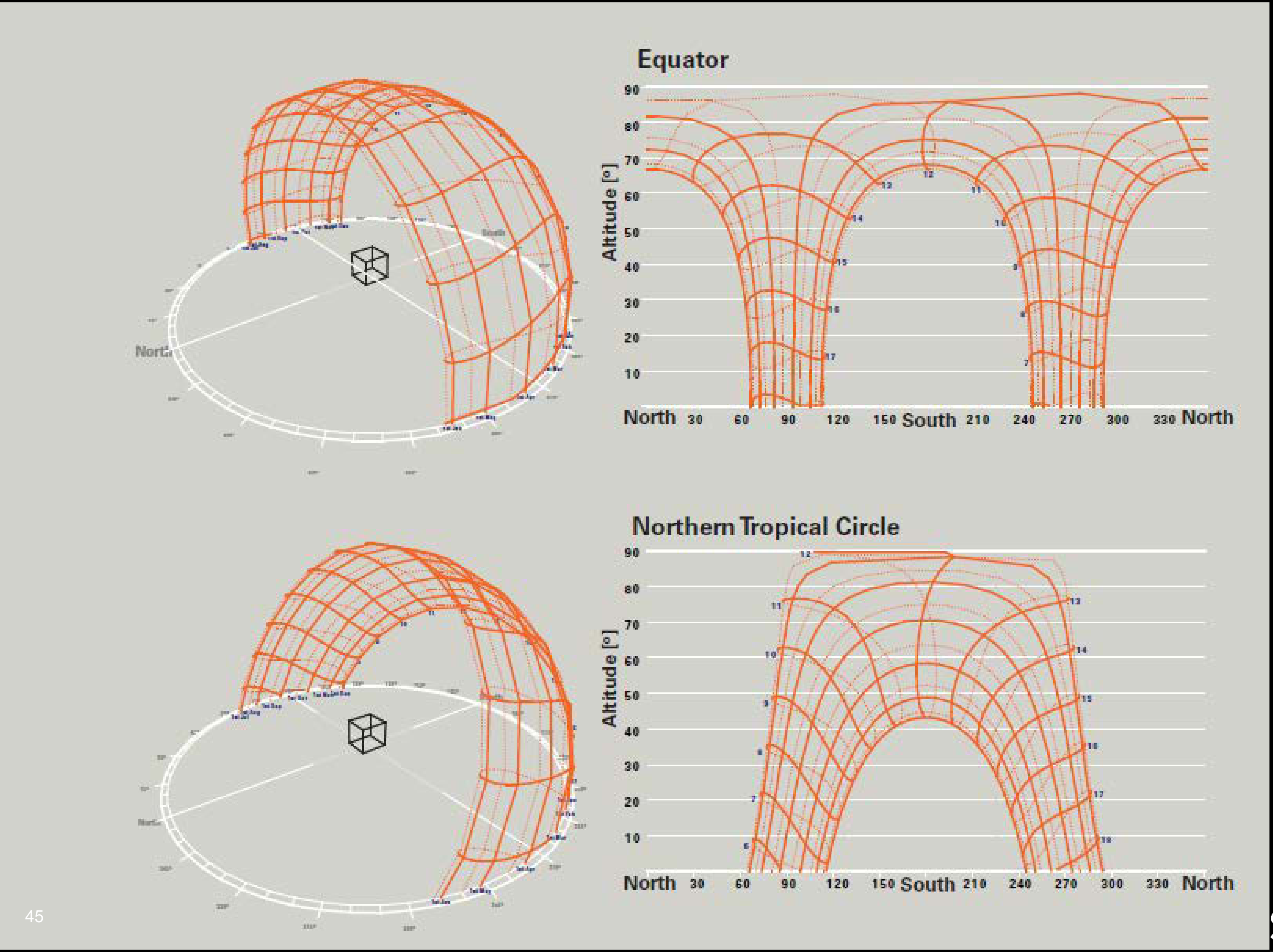
Sun Chart Examples in DIVA 4

- *Local time vs. solar time (Boston, New York City)*
- *Move from equator to pole*
- *Southern vs. Northern hemisphere*
- *Solar altitude range at noon = 90° – latitude $\pm 23.45^\circ$*
- *Example Cambridge (42.4° N): 90° – 42.4° $\pm 23.45^\circ$*

  24° to 70°

From the Equator to the Pole



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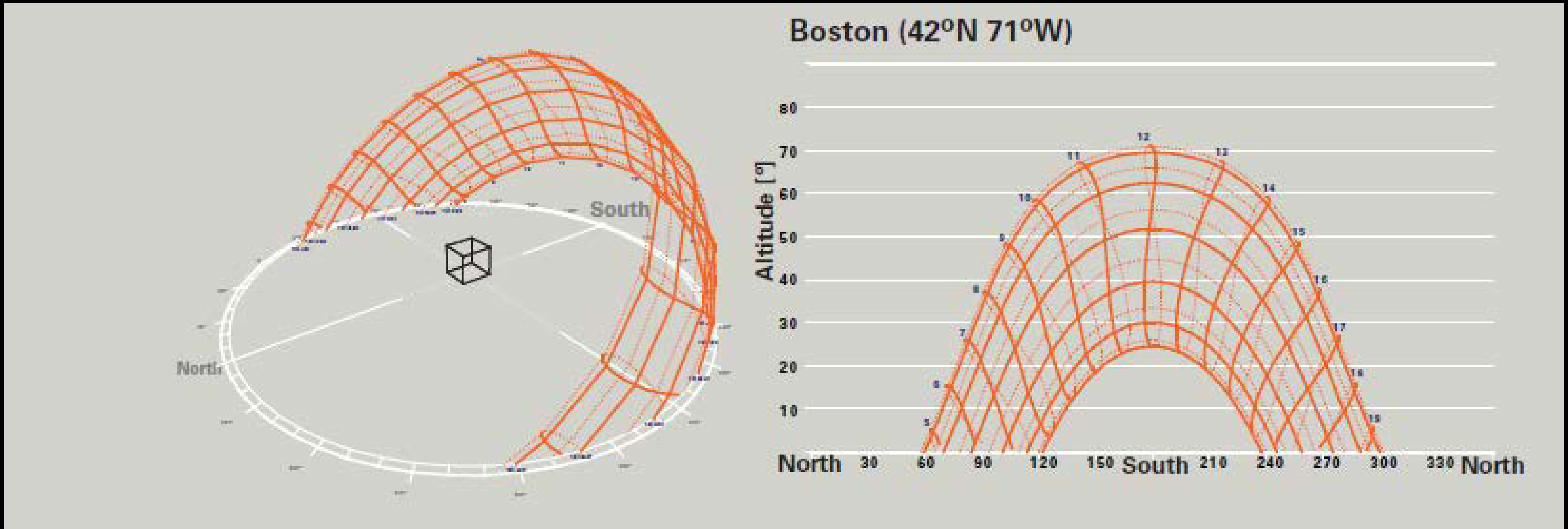
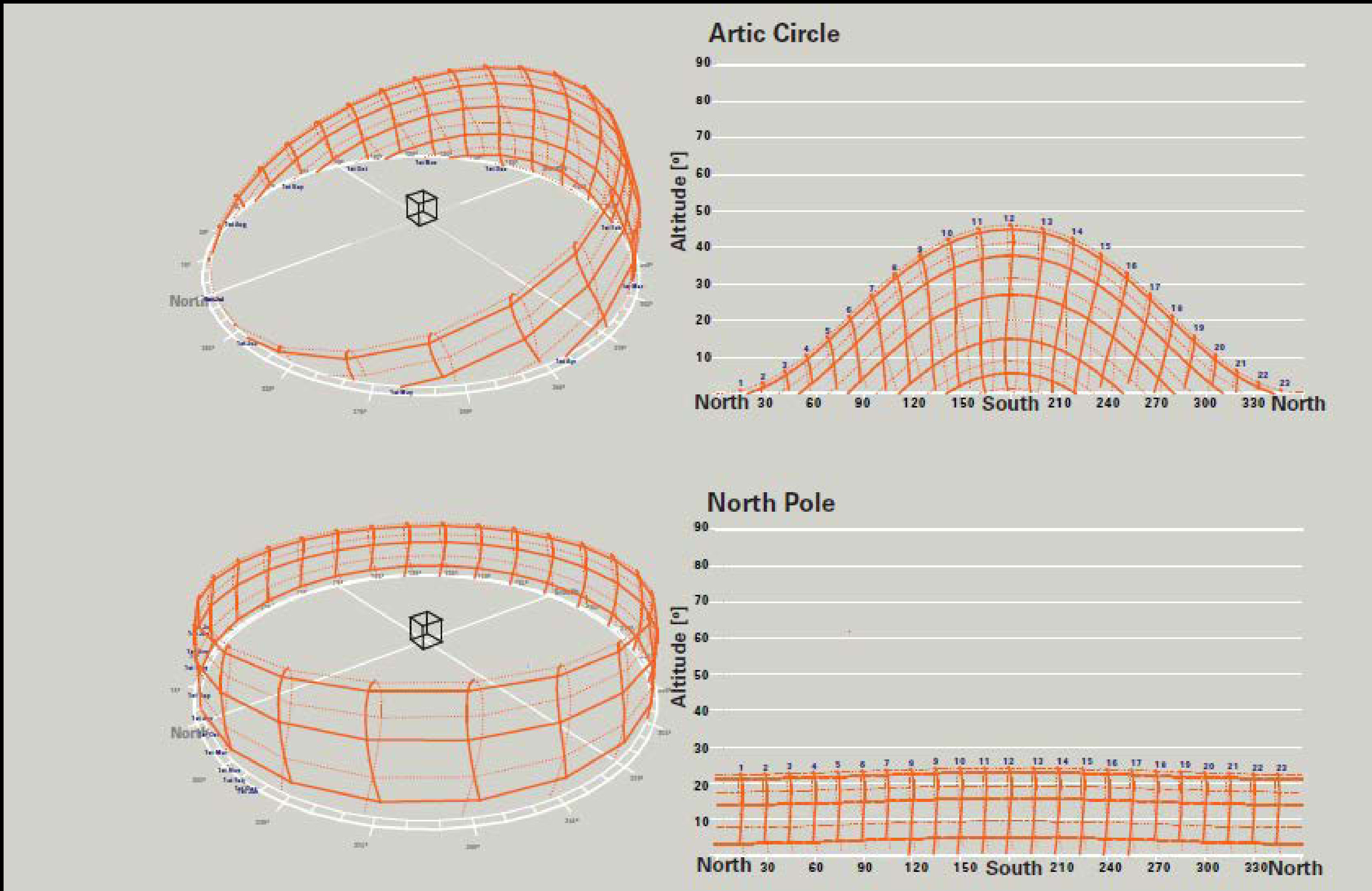
From the Equator to the Pole



From the Equator to the Pole



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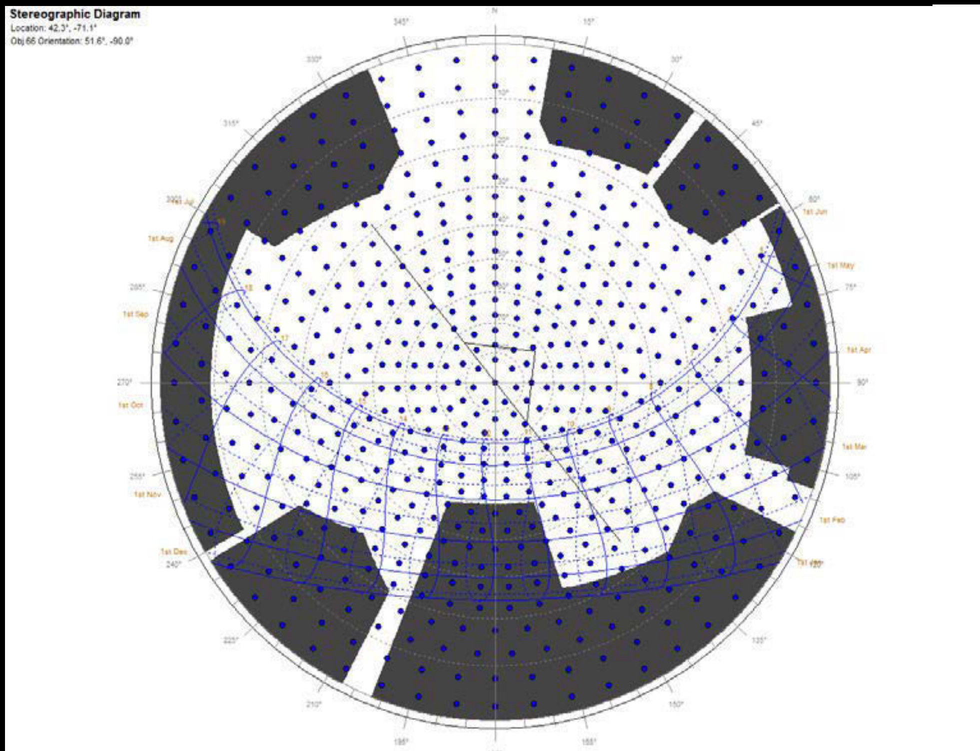
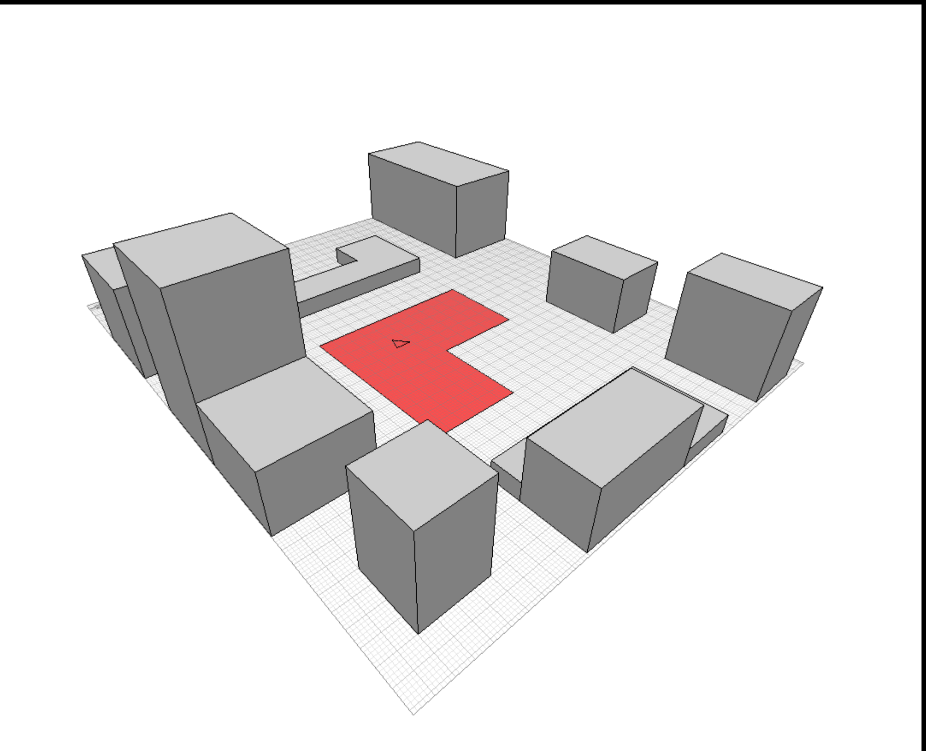
Shading Masks

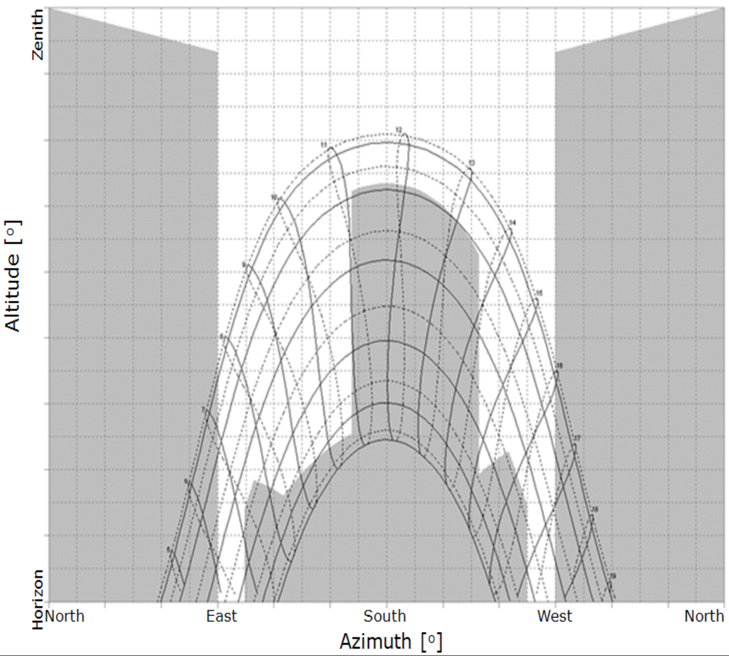


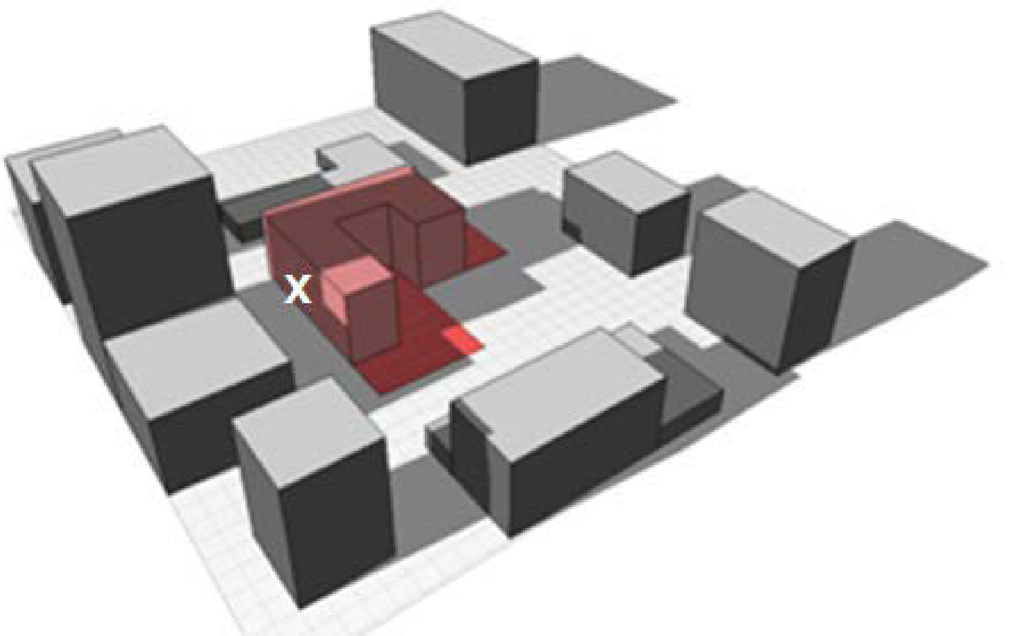


Autodesk Ecotect Shading Study

- A shading mask combines a sun path diagram with neighboring objects such as buildings and landscape that lie between a reference point and the celestial hemisphere.

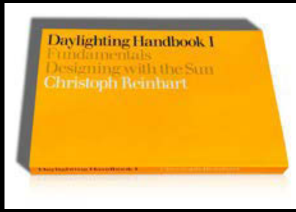
Sun Chart with Shading Mask





Autodesk Ecotect Shading Study

Weekly reading and tutorials



Chapter 3: The Source

Chapter 6: Where is the Sun?

DIVA GH 02: Sun path diagrams

Questions?

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https://ocw.mit.edu/

4.401/4.464 Environmental Technologies in Buildings Fall 2018

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